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14. ABSTRACT
Our main objective in this MURI project has been to investigate foundational and experimental techniques for enabling real-time, fault-tolerant network protocols. Our overall research goal has been to study networking architectures, services, and algorithms which require innovative quality-of-service and fault-tolerance mechanisms.We have focused on multimedia delivery in traditional client-server architectures, both in the case of the Internet and wireless networks, as well as on peer-to-peer content delivery and on mobile ad-hoc networks. The unique composition of the team has brought new synergies to the problem domain which permits the complete illumination of each newly proposed protocol from all angles, from mathematical modeling and analysis to experimental evaluation, from real-time and QoS aspects to fault-tolerance and reliability aspects. Our approach is to improve newly designed protocols through feedback from timing and fault analysis, and to develop new analysis techniques driven by new protocol designs.

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1. STATEMENT OF THE PROBLEM STUDIED

Our main objective in this MURI project has been to investigate foundational and experimental techniques for enabling real-time, fault-tolerant network protocols.

Our overall research goal has been to study networking architectures, services, and algorithms which require innovative quality-of-service and fault-tolerance mechanisms. We have focused on multimedia delivery in traditional client-server architectures, both in the case of the Internet and wireless networks, as well as on peer-to-peer content delivery and on mobile ad-hoc networks.

The unique composition of the team has brought new synergies to the problem domain which permit the complete illumination of each newly proposed protocol from all angles, from mathematical modeling and analysis to experimental evaluation, from real-time and QoS aspects to fault-tolerance and reliability aspects. Our approach is to improve newly designed protocols through feedback from timing and fault analysis, and to develop new analysis techniques driven by new protocol designs.

2. SUMMARY OF THE MOST IMPORTANT RESULTS

2.1 Results in Multimedia Communication

2.1.1 Receiver Driven Bandwidth Sharing for TCP with Applications to Video Streaming

Applications using Transmission Control Protocol (TCP), such as web-browsers, ftp, and various peer-to-peer (P2P) programs, dominate most of the Internet traffic today. In many cases, users have bandwidth-limited last mile connections to the Internet which act as network bottlenecks. Users generally run multiple concurrent networking applications that compete for the scarce bandwidth resource. Standard TCP shares bottleneck link capacity according to connection round-trip time (RTT), and consequently may result in a bandwidth partition which does not necessarily coincide with the user's desires. In this work, we developed a receiver-based bandwidth sharing system (BWSS) for allocating the capacity of last-hop access links according to user preference. Our system does not require modifications to the TCP protocol, network infrastructure or sending hosts, making it easy to deploy. By breaking fairness between flows on the access link, the BWSS can limit the throughput fluctuations of high-priority applications. We utilize the BWSS to perform efficient video streaming over TCP to receivers with bandwidth-limited last mile connections. We have demonstrated the effectiveness of our proposed system through Internet experiments [MeVlZa05, NgMeZa03, MeZa03].

2.1.2 Multiple Sender Distributed Video Streaming

With the explosive growth of video applications over the Internet, many approaches have been proposed to stream video effectively over packet switched, best-effort networks. In this work, we developed a receiver-driven protocol for simultaneous video streaming

from multiple senders to a single receiver in order to achieve higher throughput, and to increase tolerance to packet loss and delay due to network congestion. Our receiver-driven protocol employs a novel rate allocation algorithm (RAA) and a packet partition algorithm (PPA). The RAA, run at the receiver, determines the sending rate for each sender by taking into account available network bandwidth, channel characteristics, and a prespecified, fixed level of forward error correction, in such a way as to minimize the probability of packet loss. The PPA, run at the senders based on a set of parameters estimated by the receiver, ensures that every packet is sent by one and only one sender, and at the same time, minimizes the startup delay. Using both simulations and Internet experiments, we demonstrate the effectiveness of our protocol in reducing packet loss [NgZa04,NgZa03a,NgZa02a,NgZa02b,NgZa02c].

2.1.3 Path Diversity for Unicast Video Streaming

Packet loss and end-to-end delay limit delay sensitive applications over the best effort packet switched networks such as the Internet. In our previous work on distributed video streaming, we have shown that substantial reduction in packet loss can be achieved by sending packets at appropriate sending rates to a receiver from multiple senders, using disjoint paths, and by protecting packets with forward error correction. In this project, we have developed a Path Diversity with Forward error correction (PDF) system for delay sensitive applications over the Internet in which, disjoint paths from a sender to a receiver are created using a collection of relay nodes. We have developed a scalable, heuristic scheme for selecting a redundant path between a sender and a receiver, and show that substantial reduction in packet loss can be achieved by dividing packets between the default path and the redundant path. NS simulations have used to verify the effectiveness of PDF system [NgZa03b].

2.1.4 Path Diversity for Overlay Multicast Streaming

In this project, we developed a new path-diversity based scheme for application layer multicast streaming over the Internet. Rather than building simple trees as in traditional multicast, we construct multicast k-DAGs, characterized by the property that each receiver has k parents. This multiplicity of parents not only allows for streaming from multiple sources at the same time, thereby de-correlating losses, but also creates an opportunity to dynamically adapt streaming rates from these senders depending on the existing error conditions in the network. To exploit these possibilities, we use a simple rate allocation algorithm and a packet-partitioning algorithm that allows a receiver to co-ordinate the sending of data from amongst its parents. Our results show that our scheme is effective in dealing with packet losses in the network, and increases the good-put of FEC-coded video data by 15-30% [BaZa04a,BaZa04b].

2.1.5 Peer to Peer Systems

In the area of peer to peer systems, our efforts have been focused on the following:

- We developed a novel architecture and set of protocols (CITADEL) to provide content protection and propagation control in decentralized peer-to-peer systems. Our work also shows how such protection can improve the usability and scope of peer-to-peer systems.
- We considered the question of providing incentives to participating peer in such systems. We designed and evaluated 1) a reputation tracking system for peer-to-peer systems, 2) a technique to provide service differentiation using reputations as may be provided through our reputation system and 3) a robust pricing system which can be used to provide financial incentives for participation.
- Developed a novel file-centric model for the evaluation of the performance of peer-to-peer file sharing systems. The model allows for the evaluation of large-scale systems. The model is flexible and extensible and our work demonstrates its use in understanding the effect of various modes of peer behaviors.

2.1.6 Other Aspects of Multimedia Streaming

Other results in the general area of multimedia streaming include:

- Developed a novel technique for quality smoothing for layered video streaming systems and demonstrated its effectiveness in realistic video streaming experiments.
- Analyzed the feasibility of streaming video over TCP connections and provided analytic evaluation of buffer requirements based on newly developed TCP throughput formulas. Provided a systematic comparison between TCP and TFRC streaming approaches.
- Designed and evaluated a novel video streaming system for handling flash crowd receiving video from a server. The system is distinguished by its use of a simple single-description encoded video and it ability to trade-off minor video pauses for complexity and overhead.
- We developed a comparison methodology for layered and replicated stream video multicasting. Based on this methodology, we conducted a systematic comparison of the multicasting schemes. We found that the believed superiority of layered multicasting is not as clear cut as is widely believed.

2.1.7 Scheduling for Wireless Streaming

We have developed a class of rate-distortion optimized packet scheduling algorithms for streaming media by generating a number of nested substreams, with more important streams embedding less important ones in a progressive manner. Our goal is to determine the optimum substream to send at any moment in time, using feedback information from the receiver and statistical characteristics of the video. To do so, we model the streaming system as a queueing system, compute the run-time decoding failure probability of a group of picture in each substream based on effective bandwidth approach, and determine the optimum substream to be sent at that moment in time. We evaluate our scheduling scheme with various video traffic models featuring short-range dependency (SRD), long-

range dependency (LRD), and/or multifractal properties. From experiments with real video data, we show that our proposed scheduling scheme outperforms the conventional sequential sending scheme [KaZa05,KaZa03].

2.1.8 Multiple Description Video Coding for Wireless Video

Multiple description coding (MDC) is an error resilient source coding scheme that creates multiple bitstreams of approximately equal importance. The reconstructed signal based on any single bitstream has an acceptable quality. However, a higher quality reconstruction can be achieved with larger number of bitstreams. We have developed a multiple (2) description video coding scheme based on the 3 loop structure originally proposed in [1]. We modify the discrete cosine transform structure to the matching pursuits framework and evaluate performance gain using maximum likelihood (ML) enhancement when both descriptions are available. We find that ML enhancement works best for low motion sequences and results in gains of up to 1.3 dB in terms of average PSNR. Rate distortion performance is characterized. Performance comparison is made between our MDC scheme and single description coding (SDC) schemes over lossy channels, including two state Markov channels and Rayleigh fading channels. We find that MDC outperforms SDC in bursty slowly varying environments. In the case of Rayleigh fading channels, interleaving helps SDC close the gap and even outperform MDC depending on the amount of interleaving performed, at the expense of additional delay [TaZa02,TaZa01].

2.2 Results in Wireless Protocols

2.2.1 Flow Control in Wireless Networks

Rate control is an important issue in video streaming applications for both wired and wireless networks. A widely accepted rate control method in wired networks is equation based rate control, in which the TCP Friendly rate is determined as a function of packet loss rate, round trip time and packet size. This approach, also known as TFRC, assumes that packet loss in wired networks is primarily due to congestion, and as such is not applicable to wireless networks in which the bulk of packet loss is due to error at the physical layer. In this work, we have developed multiple TFRC connections as an end-to-end rate control solution for wireless video streaming. We show that this approach not only avoids modifications to the network infrastructure or network protocol, but also results in full utilization of the wireless channel. NS-2 simulations, actual experiments over 1xRTT CDMA wireless data network, and video streaming simulations using traces from the actual experiments, are carried out to validate, and characterize the performance of our proposed approach [ChZa06a,ChZa06b,ChZa05a,ChZa05b,ChZa04a,ChZa04b].

2.2.2 Adaptive Packet Scheduling in Wireless Networks]

To handle short-term channel variations, adaptive packet scheduling is an attractive course to take. The packet scheduling should provide both (1) timely delivery of real-time

(RT) packets and (2) error-free delivery of non-RT packets via fair usage of wireless link bandwidth under a dynamically-fluctuating channel condition. Packet transmissions are adaptively scheduled, depending on the predicted channel condition. Wireless channels are known to be time-varying and suffer from location-dependent and bursty errors. Since the same channel can simultaneously be seen by one mobile as bad and by another as good, this type of adaptive packet scheduling can be effective if reliable channel condition prediction is available.

The condition of a channel can be predicted based on (1) the information obtained from the physical layer; and/or (2) a hand-shaking mechanism before each packet transmission. In the second approach, before a scheduled packet transmission, the sender transmits a control packet to the receiver, then the receiver in turn replies with another control packet. Only if the sender receives a correct reply, the channel between them is predicted to be good, so the sender will send the original packet. This type of prediction is effective since most channel errors are bursty and short-lived.

If the channel condition is predicted to be bad, the original packet transmission can be deferred, and the packet which is scheduled next can be transmitted instead via a different channel. This deferment and rescheduling are done to achieve two different goals in transmitting RT and non-RT traffic, and have considered their respective QoS requirements. The basic problem here is how to schedule packet transmissions with a limited and time-varying bandwidth assigned to each mobile.

2.2.3 Adaptive Error Control in Wireless Networks

Longer time-scale channel variations cannot be handled by adaptive packet scheduling. For example, as a receiver gets farther from the sender, the channel between them will get worse on average, so they cannot maintain the communication quality, e.g., in terms of packet error probability. Power and rate control can be an attractive candidate to handle this type of channel variation effectively. In particular, achieving effective power control so as to meet end-to-end QoS requirements (especially in multi-hop ad hoc networks) in a distributed environment is an interesting and challenging problem we investigated, and extends the state-of-the-art of current distributed power control algorithms which aim to meet specified link qualities for voice and circuit-mode traffic in cellular and WLAN systems. We can use adaptive error control instead. By adapting the redundancy level used for error correction depending on the channel condition, we were able to maintain the same error performance level even under the time-varying channel condition.

Non-RT packets can rely on retransmissions while retransmission can be used in a limited manner for RT packets due to their timeliness requirement. Adaptive error control should (1) provide the required error performance to RT packets and (2) maximize throughput performance of non-RT packets while achieving error-free communications via retransmissions. The basic question here is what portion of the available bandwidth should be assigned for error-control redundancy.

2.2.4 Adaptive Bandwidth Management in Wireless Networks

Due to both user mobility and channel condition fluctuation, the available link bandwidth varies over time. Considering adaptive applications, which can change the user-perceived communication quality, or reward, depending on the assigned bandwidth, how much bandwidth to assign to each connection or application in the environment of fluctuating available bandwidth is an important problem. This problem can be geared toward maximizing the aggregate user-perceived quality or utility or reward.

To handle this, each connection or application is characterized by a utility curve, which specifies the utility level as a function of the given bandwidth. Each connection can also specify its own adaptation constraints, i.e., in terms of how often to adapt, and how much to adapt. For example, upgrading and downgrading a connection's bandwidth too often and too drastically will not be desirable if that connection is for a video communication.

2.2.5 Interplay Between Adaptive Error Control, Bandwidth Management and Packet Scheduling

All of the above three adaptive schemes should work synergistically to achieve the system goals. The bandwidth management scheme should work in the highest layer by determining how much bandwidth should be allocated to each connection based on the information like the channel condition. This information is partly coming from both adaptive error control and packet scheduling.

Adaptive error control determines how strong error control should be, thus determining how much bandwidth is utilized for actual information transmission out of the total assigned bandwidth to a connection. Adaptive packet scheduling works in the lowest layer by scheduling actual packet transmissions based on the available actual bandwidth for each connection.

2.2.6 Handoff in Wireless Networks

For the cellular wireless networks, we have developed new handoff schemes for CDMA systems. Our proposed handoff schemes can significantly decrease both the number of dropped handoff calls and the number of blocked calls without degrading the quality of communication service and the soft handoff process. Two patents on these topics have been granted.

We have also studied the performance, availability and performability of various handoff techniques for different arrival models and load conditions. In general, wireless systems are characterized by their scarce radio sources which limit not only the service offering but also the QoS. Furthermore, service degradation can be caused by component failures, software failures and human errors in operation in the wireless system. Compared with wired networks, wireless networks need to deal with disconnects due to handoff, noise and interference, fast (slow) fading, blocked and weak signals and run-down batteries. In addition, the performance and availability of a wireless system is affected by the outage-

and-recovery of its supporting functional units. From the designer and operator's point of view, it is of great importance to take these factors into account integratively. For wireless cellular networks, we have developed two level hierarchical models with handoff and channel failures. Further, for a TDMA system consisting of a base repeaters and a control channel, we have build a hierarchical Markov chain model for automatic protection switching.

2.2.7 QoS in IEEE 802.11e Supplements

In the area of IEEE 802.11 wireless LANs, we have tackled a variety of problems dealing with scheme for optimal training of wireless channels, reliability and dependability studies of IEEE 802.11 protocols. In particular, we have evaluated the capability of the enhanced point coordination function (EPCF) for QoS in the IEEE 802.11e supplements, to support VoIP applications. Our results show that in the scenario where VoIP calls are made between wireline and wireless networks, the EPCF operation mode provides low end to end delays for voice calls and its performance is not sensitive to background best effort traffic.

2.2.8 Shadow Regions for IEEE 802.11 b/g

The presence of physical obstacles and radio interference results in the so called "shadow regions" in wireless networks. When a mobile station roams into a shadow region, it loses its network connectivity. In cellular networks, in order to minimize the connection unreliability, careful cell planning is required to prevent the occurrence of the shadow regions in the first place. In 802.11b/g wireless LANs, however, due to the limited frequency spectrum, it is not always possible to prevent a shadow region by adding another cell at a different frequency. We have proposed the alternate approach of tolerating the existence of ``shadow regions" as opposed to prevention in order to enhance the connection dependability. A redundant access point (AP) is placed in the shadow region to serve the mobile stations that roam into that region. To evaluate the dependability of the network under study, we have presented the reliability, availability and survivability analysis of the two configurations and compare them with the scheme with no redundancy.

2.3 Results in Mobile Ad hoc Networks

2.3.1 Multi-Path Unicast Streaming in Wireless Ad hoc Networks

In this project, we developed a novel multi-path selection framework for streaming over wireless ad hoc networks. Our approach is to approximately estimate the concurrent packet drop probability of two paths by taking into account the interference between different links, and to select the best path pair based on that estimation. We prove the optimal path selection problem to be NP-hard, and propose a heuristic solution, whose performance is shown to be close to that of the optimal solution, while significantly outperforming other heuristic protocols [WeZa7a,WeZa6b,WeZa4a,WeZa4b].

2.3.2 Multiple Tree Video Multicast in Wireless Ad hoc Networks

In this project, we developed multiple tree construction schemes and routing protocols for video streaming over wireless ad hoc networks. The basic idea is to split the video into multiple parts and send each part over a different tree, which are constructed to be disjoint with each other so as to increase robustness to loss and other transmission degradations. Specifically, we propose two novel multiple tree multicast protocols. Our first scheme constructs two disjoint multicast trees in a serial, but distributed fashion, and is referred to as Serial MDTMR. It achieves reasonable tree connectivity while maintaining disjointness of two trees. In order to reduce routing overhead and construction delay, we further propose parallel multiple nearly-disjoint multicast trees protocol, which is also shown to achieve reasonable tree connectivity. Simulations show that resulting video quality for either scheme is significantly higher than that of single tree multicast, with similar routing overhead and forwarding efficiency [WeZa07a,WeZa07b, WeZa6a,WeZa4a,WeZa4c].

2.3.3 Highly Partitioned and Sparse Mobile Ad hoc Networks

In the area of highly partitioned and sparse mobile ad hoc networks, we have developed the following results:

- We conceived of a new paradigm for message delivery utilizing predictable, non-random movement of some nodes called "Message Ferries". This defines a novel store-carry-and-forward delivery paradigm that shows considerable promise in such partitioned networks that arise in battle-filed and disatser relief environments.
- We developed and evaluated a Ferry routing algorithm suitable for partitioned networks with mobile nodes.
- We have developed and evaluated two approaches for ferry routing to deal with mobile nodes. One approach uses fixed ferry movement with proactive node movement, the other uses proactive ferry movements.

2.4 Results in Fault Tolerant Communication Algorithms

We have focused on the development of powerful fault- tolerant communication algorithms, the analysis of such algorithms, and the development of semantic foundations and tools to support the algorithms and analysis work. We made a great deal of progress in all three directions, as documented in the list of publications presented below. Here are some highlights.

2.4.1 Algorithms

We developed the Rambo algorithms for implementing atomic memory in highly dynamic networks [RAMBOI, RAMBOII, Gilbert-MS, RAMBOII-tr].

We developed the Virtual Node approach to programming applications in mobile ad hoc networks [DGLSW, DGLSW-jour, BGLNNS, DGLLN-opodis05, LMN-tr, LMN, DGLLN-allerton, DLLN, DGLLN-podc05]

Basically, this approach defined a new programming abstraction for mobile networks: a virtual network consisting of mobile client nodes and simple virtual nodes. A virtual node may be an atomic object, or a timed or untimed I/O automaton, and may reside at a fixed geographical location or may move according to a predictable path. Our work defines several kinds of virtual node layers and shows how to implement them in mobile networks. It also shows how the abstraction can be used to implement various applications, including highly fault-tolerant atomic read/write memory, geographical and point-to-point message routing, location services, intruder tracking, robot coordination, and vehicle coordination (e.g., a virtual traffic light).

We developed a new strategy for fault-tolerant message flooding in (possibly mobile) sensor networks [LivadasLynch]. The algorithm tolerates a variety of failures and network changes, and achieves quite low communication cost. The basic idea is to combine two kinds of communication: flood newly-acquired information immediately, while monitoring in the background to detect when neighboring nodes should be brought up to date.

We defined the problem of "gradient clock synchronization" for mobile/sensor networks [FanLynch-gradient, FL04, FCL04] which says that that clocks of nearby processors always be closely synchronized. We proved a fundamental result saying that this property is impossible to achieve under standard network assumptions. However, we were able to construct a practical clock synch algorithm that makes use of GPS when available and that satisfies the gradient property "almost always".

We have also developed many other algorithms for problems such as tracking in sensor networks [DANL-stalk], distributed consensus in Byzantine settings [ACKM-podc04], and clustering in sensor networks [MR04].

2.4.2 Semantics and Verifications

We deveoped the Timed Input/Output Automata (TIOA) mathematical modeling framework for analyzing timed systems, such as communication protocols [KLSV-monograph,KLSV-rtss]. In fact, we completed a comprehensive monograph on the TIOA model, formulated to be consistent with our recently-developed Hybrid I/O Automata (HIOA) modeling framework. The monograph includes the basic theory, including composition, levels of abstraction, rely-guarantee reasoning, safety vs. liveness, region constructions, etc. Everything is illustrated with simple examples. This is intended to be useful as a general handbook about timed system modeling, for both theoreticians and system developers. It includes the complete theory, as well as suggestions for how to use it to model systems.

We developed techniques for rely-guarantee reasoning for TIOA [KL04]. We developed techniques for stability analysis using HIOA [MitraLiberzon].

We also developed Probabilistic I/O Automata models, with emphasis on compositionality properties. [CheungLSV-short, CheungLSV-long, [LSV-concur]. We elucidated the problems with earlier definitions for composition and external behavior for PIOAs: those definitions allow the entity that schedules different components so much power that the entire internal branching structure of the PIOAs is exposed. Our new solution to this problem is to restrict the scheduler's power so that its choices can depend only on externally-visible behavior of the components. As an important first step, we considered a restricted form of PIOA, "switched automata", which explicitly control their own scheduling, passing control from one to the other via special control actions. We proved powerful compositionality results for this restricted model. More recently, we have extended this work to the more general "task-PIOA" model, which appears to be suitable for modeling security protocols.

2.4.3 Tools

We completed our work on code generation from I/O Automata (IOA) Programs [Tauber,TauberLT,GLTV,TauberGarland,VTTL]. We can now generate runnable code (Java interacting with MPI) for our LAN, automatically and directly from IOA models for distributed algorithms. The algorithm models can be proved correct and analyzed for performance using a range of techniques, including hand analysis, interactive theorem-proving, and model-checking. Thus, we essentially have a method of generating verified code.

We then extended the IOA language to TIOA, which has features to model time-passage, using algebraic and differential equations and inequalities to describe "trajectories" of state evolution over time. We have developed versions of various tools to analyze TIOA programs: a simulator, a translator to the PVS theorem-prover, and a translator to the UPPAAL model-checker. We are currently engineering these tools, under the auspices of an AFOSR STTR, for wider use.

2.5 Results in Design and Implementation of Real Time Software

2.5.1 Meeting real time requirements in software

Papers related to this topic include [J1,J2,C1,C2,C3,C4,C5,C6,C7,C8]. Below is the summary of main results:

Giotto: We developed Giotto, a platform-independent language for specifying software for high-performance control applications. A Giotto program explicitly specifies the exact real-time interaction of software components with the physical world. The Giotto compiler automatically generates timing code that ensures the specified behavior on a given platform. We illustrated the Giotto methodology by reimplementing the controller

for an autonomously flying model helicopter originally developed at ETH Zurich. We demonstrated that Giotto introduces a negligible overhead, and at the same time increases the reliability and reusability of the control software.

Schedule Carrying Code: We introduced the paradigm of schedule-carrying code (SCC). A hard real-time program can be executed on a given platform only if there exists a feasible schedule for the real-time tasks of the program. Traditionally, a scheduler determines the existence of a feasible schedule according to some scheduling strategy. With SCC, a compiler proves the existence of a feasible schedule by generating executable code that is attached to the program and represents its schedule. An SCC executable is a real-time program that carries its schedule as code, which is produced once and can be revalidated and executed with each use. We evaluated SCC both in theory and practice. In theory, we gave two scenarios, of non-preemptive and distributed scheduling for Giotto programs, where the generation of a feasible schedule is hard, while the validation of scheduling instructions that are attached to the programs is easy. In practice, we implemented SCC and show that explicit scheduling instructions can reduce the scheduling overhead up to 35% and can provide an efficient, flexible, and verifiable means for compiling Giotto programs on complex architectures, such as the TTA.

A Typed Assembly Language for Real Time: We presented a type system for E code, which is an assembly language that manages the release, interaction, and termination of real-time tasks. E code specifies a deadline for each task, and the type system ensures that the deadlines are path-insensitive. We show that typed E programs allow, for given worst-case execution times of tasks, a simple schedulability analysis. Moreover, the real-time programming language Giotto can be compiled into typed E code. This shows that typed E code identifies an easily schedulable yet expressive class of real-time programs. We have extended the Giotto compiler to generate typed E code, and enabled the run-time system for E code to perform a type and schedulability check before executing the code.

Event-driven Programming with Logical Exceution Times: We presented an extension of Giotto, called xGiotto, for programming applications with hard real-time constraints. Like its predecessor, xGiotto is based on the LET (logical execution time) assumption: the programmer specifies when the outputs of a task become available, and the compiler checks if the specification can be implemented on a given platform. However, while the predecessor language Giotto was purely time-triggered, xGiotto accommodates also asynchronous events. Indeed, through a mechanism called event scoping, events are the main structuring principle of the new language. The xGiotto compiler and run-time system implement event scoping through a tree-based event filter. The compiler also checks programs for determinism (absence of race conditions) and time safety (schedulability).

2.5.2 Modeling and analysis of the real time behavior of the system

This work is described in detail in [J3,J4,J5,C15,C16,C17,C18,C19,C20]. Below, we provide a summary of main results:

Hybrid systems: A hybrid system is a dynamical system with both discrete and continuous state changes. For analysis purposes, it is often useful to abstract a hybrid system in a way that preserves the properties being analyzed while hiding the details that are of no interest. We showed that interesting classes of hybrid systems can be abstracted to purely discrete systems while preserving all properties that are definable in temporal logic. In this way, we could solve verification and control problems on hybrid systems.

Real-time control: We argued that models where a controller can cause an action at any point in dense (rational or real) time are problematic, by presenting an example where the controller must act faster and faster, yet causes no Zeno effects (say, the control actions are at times 0, 0.5, 1, 1.25, 2, 2.125, 3, 3.0625, ...). Such a controller is, of course, not implementable in software. Such controllers are avoided by formulations where the controller can cause actions only at discrete (integer) points in time. While the resulting control problem is well-understood if the time unit, or "sampling rate" of the controller, is fixed a priori, we defined a novel, stronger formulation: the discrete-time control problem with unknown sampling rate asks if a sampling controller exists for some sampling rate. We proved that this problem is undecidable.

Massacio: Based on hybrid systems, we developed Masaccio, a formal model for real-time components which are built from atomic discrete components (difference equations) and atomic continuous components (differential equations) by parallel and serial composition, arbitrarily nested. Each system component consists of an interface, which determines the possible ways of using the component, and a set of executions, which define the possible behaviors of the component in real time.

Assume-guarantee reasoning for real time: The assume-guarantee paradigm is a powerful divide-and-conquer mechanism for decomposing a verification task about a system into subtasks about the individual components of the system. The key to assume-guarantee reasoning is to consider each component not in isolation, but in conjunction with assumptions about the context of the component. Assume-guarantee principles were known for purely concurrent contexts, which constrain the input data of a component, as well as for purely sequential contexts, which constrain the entry configurations of a component. We developed an assume-guarantee principle for mixed parallel-serial contexts, and for mixed discrete-continuous processes. This is necessary for the component-based design and analysis of embedded software systems which interact with real-world environments. Using an example of two cooperating robots, we showed refinement between a high-level model which specifies continuous timing constraints and an implementation which relies on discrete sampling.

2.5.3 Composition of real-time and stochastic components

This work is described in detail in [C9,C10,C11,C12,C13,C14]. Below is the summary of main results;

Timed interfaces: We developed a theory of timed interfaces, which is capable of specifying both the timing of the inputs a component expects from the environment, and the timing of the outputs it can produce. Two timed interfaces are compatible if there is a way to use them together such that their timing expectations are met. The theory provides algorithms for checking the compatibility between two interfaces and for deriving the composite interface; the theory can thus be viewed as a type system for real-time interaction. Technically, a timed interface is encoded as a timed game between two players, representing the inputs and outputs of the component. The algorithms for compatibility checking and interface composition are thus derived from algorithms for solving timed games.

Timed games: Timed games are two-person games played in real time, in which the players decide both which action to play, and when to play it. Timed games differ from untimed games in two essential ways. First, players can take each other by surprise, because actions are played with delays that cannot be anticipated by the opponent. Second, a player should not be able to win the game by preventing time from diverging. We presented a model of timed games that preserves the element of surprise and accounts for time divergence in a way that treats both players symmetrically and applies to all omega-regular winning conditions. We proved that the ability to take each other by surprise adds extra power to the players. For the case that the games are specified in the style of timed automata, we provided symbolic algorithms for their solution with respect to all omega-regular winning conditions. We also showed that for these timed games, memory strategies are more powerful than memoryless strategies already in the case of reachability objectives.

Compositional models for probabilistic systems: We developed a compositional trace-based model for probabilistic systems. The behavior of a system with probabilistic choice is a stochastic process, namely, a probability distribution on traces, or "bundle." Consequently, the semantics of a system with both nondeterministic and probabilistic choice is a set of bundles. The bundles of a composite system can be obtained by combining the bundles of the components in a simple mathematical way. Refinement between systems is bundle containment. We achieved assume-guarantee compositionality for bundle semantics by introducing two scoping mechanisms. The first mechanism, which is standard in compositional modeling, distinguishes inputs from outputs and hidden state. The second mechanism, which arises in probabilistic systems, partitions the state into probabilistically independent regions.

2.6 Results on Software Aging, Rejuvenation and Preventive Maintenance

Our research on software aging and software rejuvenation focused on developing novel methods and techniques to detect and fix slowly creeping problems in computer systems before they build up and cause the system to hang or crash. The software aging phenomenon has been observed in personal computers, safety-critical systems as well as

high-availability systems and dealing with this is critical to system availability and performance.

Software rejuvenation is a means of gracefully terminating an application, without corrupting or losing data, and restarting it in a clean state. Our papers were the first to clearly document the phenomenon of software aging based on real system data and we have proposed new techniques to determine optimal times for software rejuvenation to obtain maximum availability and minimum performance loss.

The work on software aging and software rejuvenation has been well accepted both by research community as well as by industry. Our papers in the area of software rejuvenation have been cited extensively by other researchers in leading international conferences and journals, and we have presented several well-attended tutorials on this topic.

In the area of preventive maintenance, we have worked on both time-based and inspection-based preventive maintenance. Preventive maintenance of operational software systems/hardware is used specifically to counteract degradation phenomenon (increasing failure rate with time). However, preventive maintenance incurs an overhead in terms of downtime and cost, and these must be traded off with the cost of failures to obtain maximum benefits. We have developed analytical models employing inspection-based preventive maintenance, through continuous time Markov chains, semi-Markov and Markov Regenerative Process (MRGP) with a subordinated semi-Markov reward process, considering preemptive-resume type transitions. In the case of Markov and semi-Markov models, we have developed closed-form solutions while in the case of MRGP, we have solved the models numerically. The MRGP models are solved for steady state as well as transient conditions and expressions for expected downtime and expected cost are derived. Numerical examples are presented to illustrate the applicability of the models. With the help of these models, optimal strategies for preventive maintenance techniques could be formulated.

3. BIBLIOGRAPHY

[MeVlZa05] P. Mehra, C. D. Vleeschouwer, and A. Zakhor, "Receiver-Driven Bandwidth Sharing for TCP and its Application to Video Streaming", IEEE Transactions on Multimedia, Vol. 7, No. 4, August 2005, pp. 740-752.

[NgMeZa03] T. Nguyen, P. Mehra, and A. Zakhor, "Path Diversity and Bandwidth Allocation for Multimedia Streaming" in International Conference on Multimedia and Expo, Vol. 1, Baltimore, Maryland, July 2003, pp. 1-4. (invited paper)

[MeZa03] P. Mehra and A. Zakhor, "TCP-Based Video Streaming Using Receiver-Driven Bandwidth Sharing" in 13th International Packet Video Workshop, Nantes, France, April 2003.

[NgZa04] T. Nguyen and A. Zakhor, "Multiple Sender Distributed Video Streaming" in IEEE Transactions on Multimedia, Vol. 6, No. 2, April 2004, pp. 315 - 326.

[NgZa03a] T. Nguyen and A. Zakhor, "Matching Pursuits Based Multiple Description Video Coding for Lossy Environments" in International Conference on Image Processing 2003, Vol. 1, Barcelona, Spain, September 2003, pp.57-60. (invited paper)

[NgZa03b] T. Nguyen and A. Zakhor, "Path Diversity with Forward Error Correction (PDF) System for Packet Switched Networks" in Proceedings of IEEE INFOCOM 2003, San Francisco, California, April 2003

[NgZa02a]T. Nguyen and A. Zakhor, "Protocols for Distributed Video Streaming" in International Conference on Image Processing 2002, Rochester, New York, September 2002, Vol. 3, p. 185-189.

[NgZa02b] T. Nguyen and A. Zakhor, "Distributed Video Streaming with Forward Error Correction" in Packet Video 2002, Pittsburgh, April 2002. (Best Paper Award.)

[NgZa02c] T. Nguyen and A. Zakhor, "Distributed video streaming over internet" in Multimedia Computing and Networking 2002, Proceedings of SPIE, San Jose, California, January 2002, Vol. 4673, p. 186-195.

[BaZa04a] M. Bansal and A. Zakhor, "Path Diversity for Overlay Multicast Streaming", Packet Video Workshop, Irvine, CA, Dec. 2004.

[BaZa04c] M. Bansal and A. Zakhor, "Path Diversity Based Techniques for Resilient Overlay Multimedia Multicast", Picture Coding Symposium (PCS) 2004, San Francisco, CA, Dec. 2004. (invited paper)

[KaZa05] S. H. Kang and A. Zakhor, "Effective Bandwidth Based Scheduling for Streaming Multimedia", IEEE Transactions on Multimedia, Vol. 7, No. 6, December 2005, pp. 1139-1148.

[KaZa03] S. H. Kang and A. Zakhor, "Effective Bandwidth Based Scheduling for Streaming Multimedia" in International Conference on Image Processing 2003, Barcelona, Spain, Vol. 2, pp. III-633-636, September 2003.

[TaZa02] X. Tang and A. Zakhor, "Matching Pursuit Multiple Description Coding for Wireless Video", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 12, No. 6, June 2002, pp. 566-575.

[TaZa01] X. Tang and A. Zakhor, "Matching pursuits multiple description coding for wireless video" in Proceedings of the International Conference on Image Processing, Thessaloniki, Greece, October 2001, Vol. 1, p. 926-929.

[ChZa06a] M. Chen and A. Zakhor, "Multiple TFRC Connections Based Rate Control for Wireless Networks," IEEE Trans. on Multimedia, Vol. 8 , No. 5, Oct. 2006, pp. 1045-1062.

[ChZa05a] M. Chen and A. Zakhor, "Rate Control for Streaming Video over Wireless", IEEE Wireless Communications, Vol. 12, Issue 4, Aug. 2005, pp. 32-41 (invited paper)

[ChZa06b] M. Chen and A. Zakhor, "Flow Control over Wireless Network and Application Layer Implementation", Infocom 2006, Barcelona, Spain, April 2006.

[ChZa05b] M. Chen and A. Zakhor, "AIO-TFRC: A light-weighted rate control scheme for streaming over wireless" in IEEE WirelessCom Symposium on Multimedia over Wireless 2005, Maui, Hawaii, June 2005, Vol. 2, pp. 1124 - 1129. (invited paper)

[ChZa04a] M. Chen and A. Zakhor, "Transmission Protocols for Streaming Video over Wireless" in International Conference on Image Processing 2004, Singapore, October 2004, pp. 1743-1746. (invited paper)

[ChZa04b] M. Chen and A. Zakhor, "Rate Control for Streaming Video over Wireless" in INFOCOM, HongKong, P.R.China, Mar. 2004.

[WeZa07a] W. Wei and A. Zakhor, "Multipath Unicast and Multicast Video Communication over Wireless Ad Hoc Networks" to appear in Broadband Mobile Multimedia: Techniques and Applications, Auerbach Publications, CRC Press, edited by Yan Zhang, Shiwen Mao, Laurence T. Yang, and Thomas M. Chen, 2007.

[WeZa07b] W. Wei and A. Zakhor, "Multiple Tree Video Multicast over Wireless Ad Hoc Networks," IEEE Transactions on Circuits, Systems and Video Technology, Vol. 17, No. 1, Jan. 2007, pp. 2-15.

[WeZa06a] A. Zakhor and W. Wei, "Multiple Tree Video Multicast Over Wireless Ad Hoc Networks", International Conference on Image Processing, Atlanta, Georgia, September 2006.

[WeZa06b] W. Wei and A. Zakhor, "Path Selection For Multi-path Streaming in Wireless Ad Hoc Networks", International Conference on Image Processing, Atlanta, Georgia, September 2006.

[WeZa04a] W. Wei and A. Zakhor, "Multipath Unicast and Multicast Video Communication over Wireless Ad Hoc Networks" in International Conference on Broadband Networks (Broadnets) 2004, San Jose, CA, October 2004, pp. 496-505. (invited paper)

[WeZa04b] W. Wei and A. Zakhor, "Robust Multipath Source Routing Protocol (RMPSR) for Video Communication over Wireless Ad Hoc Networks" in International Conference on Multimedia and Expo 2004, pp:1379 - 1382, Taipei, Taiwan, June 2004.

[WeZa04c] W. Wei and A. Zakhor, "Connectivity for Multiple Multicast Trees in Ad Hoc Networks" in International Workshop on Wireless Ad-hoc Networks, Oulu, Finland, June 2004, pp. 270-274.

[ACKM-podc04] Ittai Abraham, Gregory Chockler, Idit Keidar and Dahlia Malkhi. Byzantine Disk Paxos: Optimal Resilience with Byzantine Shared Memory. Proceedings of the 23st ACM Symposium on Principles of Distributed Computing (PODC'04), St. John's Newfoundland, Canada, pages 226-235, July 2004.

[BGLNNS] Matthew Brown, Seth Gilbert, Nancy Lynch, Calvin Newport, Tina Nolte, and Michael Spindel. The Virtual Node Layer: A Programming Abstraction for Wireless Sensor Networks. Proceedings of the International Workshop on Wireless Sensor Network Architecture (WWSNA), Cambridge, MA, April, 2007.

[CheungLSV-short] Ling Cheung, Nancy Lynch, Roberto Segala, and Frits Vaandrager. Switched Probabilistic I/O Automata. In Z. Liu and K. Araki, editors, Proceedings First International Colloquium on Theoretical Aspects of Computing (ICTAC2004), Guiyang, China, September 2004, volume 3407 of Lecture Notes in Computer Science, pages 494-510, Springer-Verlag, 2005.

[CheungLSV-long] Ling Cheung, Nancy Lynch, Roberto Segala, and Frits Vaandrager. Switched Probabilistic I/O Automata. Nijmegen Institute for Computing and Information Sciences (NIII) Technical Report NIII-R0437, Catholic University of Nijmegen, Nijmegen, The Netherlands, September 2004.

[DANL-stalk] Murat Demirbas, Anish Arora, Tina Nolte, and Nancy Lynch. Brief Announcement: STALK: A Self-Stabilizing Hierarchical Tracking Service for Sensor Networks. Proceedings of the 23rd Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2004), July 25-28, 2004, St. John's, Newfoundland, Canada.

[DGLSW] Shlomi Dolev, Seth Gilbert, Nancy Lynch, Alex Shvartsman, and Jennifer Welch. GeoQuorums: Implementing Atomic Memory in Ad Hoc Networks. In Faith Fich, editor, Distributed Computing (DISC 2003: 17th International Symposium on Distributed Computing, Sorrento, Italy, October, 2003), volume 2848 of Lecture Notes in Computer Science, pages 306-320, Springer-Verlag, 2003.

[DGLSW-jour] Shlomi Dolev, Seth Gilbert, Nancy A. Lynch, Alex A. Shvartsman, and Jennifer L. Welch. GeoQuorums: Implementing Atomic Memory in Mobile Ad Hoc Networks. Distributed Computing, Special Issue DISC03, 18(2):125-155, 2005. Also, Technical Report MIT-LCS-TR-900a, CSAIL, Massachusetts Institute of Technology, Cambridge, MA, 2004.

[DGLLN-opodis05] Shlomi Dolev, Seth Gilbert, Limor Lahiani, Nancy Lynch, and Tina Nolte. Timed Virtual Stationary Automata for Mobile Networks. 9th International Conference on Principles of Distributed Systems (OPODIS 2005), Pisa, Italy, December 12-14, 2005.

[DGLLN-allerton] Shlomi Dolev, Seth Gilbert, Limor Lahiani, Nancy Lynch, and Tina Nolte. Timed Virtual Stationary Automata for Mobile Networks. Allerton Conference

2005: Forty-Third Annual Allerton Conference on Communication, Control, and Computing, September 2005. Invited paper.

[DLLN] Shlomi Dolev, Limor Lahiani, Nancy Lynch, and Tina Nolte. Self-Stabilizing Mobile Node Location Management and Message Routing. SSS 2005: Seventh International Symposium on Self-Stabilizing Systems, Barcelona, Spain, October 2005. Also,Technical Report MIT-LCS-TR-999, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA, August 2005.

[DGLLN-podc05] Shlomi Dolev, Seth Gilbert, Limor Lahiani, Nancy Lynch, and Tina Nolte. Virtual Stationary Automata for Mobile Networks (Extended Abstract). Technical Report MIT-LCS-TR-979, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, January 2005.

[FanLynch-gradient] Rui Fan and Nancy Lynch. Gradient Clock Synchronization. Distributed Computing, 18(4):255-266, March 2006.

[FL04] Rui Fan and Nancy Lynch. Gradient Clock Synchronization. Proceedings of the Twenty-Third Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing, St. John's, Newfoundland, Canada, July 25-58, 2004.

[FCL04] Rui Fan, Indraneel Chakraborty, and Nancy Lynch. Clock Synchronization for Wireless Networks. In Teruo Higashino, editor, Principles of Distributed Systems: OPODIS 2004: 8th International Conference on Principles of Distributed Systems, Grenoble, France, December 15-17, 2004, volume 3544 of Lecture Notes in Computer Science}, pages 400-414, 2005. Springer.

[GLTV] Stephen Garland, Nancy Lynch, Joshua Tauber, and Mandana Vaziri. IOA User Guide and Reference Manual. Technical Report MIT-LCS-TR-961, MIT CSAIL, July 2004.

[RAMBOII] Seth Gilbert, Nancy Lynch, and Alex Shvartsman. RAMBO II: Rapidly Reconfigurable Atomic Memory for Dynamic Networks. Proceedings of the International Conference on Dependable Systems and Networks (DSN), San Francisco, CA, pages 259-268, June 22nd - 25th, 2003.

[Gilbert-MS] Seth Gilbert. RAMBO II: Rapidly Reconfigurable Atomic Memory for Dynamic Networks. Masters Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, August 2003.

[RAMBOII-tr] Seth Gilbert, Nancy Lynch, and Alex Shvartsman. RAMBO II: Implementing atomic memory in dynamic networks, using an aggressive reconfiguration strategy. Technical Report MIT-CSAIL-TR-890, CSAIL, Massachusetts Institute Technology, Cambridge, MA, 2004.

[KL04] Dilsun K. Kaynar and Nancy A. Lynch. Decomposing Verification of Timed I/O Automata. Formal Techniques, Modelling and Analysis of Timed and Fault Tolerant Systems: Joint International Conferences on Formal Modeling and Analysis of Timed Systems, FORMATS 2004, and Format Techniques in Real-Time and Fault-Tolerant Systems, FTRTFT 2004, Grenoble, France, September 22-24, 2004. Volume 3253 of Lecture Notes in Computer Science, pages 84-101, Springer-Verlag, 2004.

[KLSV-monograph] Dilsun K. Kaynar, Nancy Lynch, Roberto Segala, and Frits Vaandrager. The Theory of Timed I/O Automata. Synthesis Lectures on Computer Science, Morgan Claypool Publishers, 2006. Revised and shortened version of Technical Report MIT-LCS-TR-917a (from 2004)

[KLSV-rtss] Dilsun K. Kaynar and Nancy Lynch and Roberto Segala and Frits Vaandrager. Timed I/O Automata: A Mathematical Framework for Modeling and Analyzing Real-Time Systems. RTSS 2003: The 24th IEEE International Real-Time Systems Symposium, Cancun, Mexico, pages 166-177, December, 2003.

[LivadasLynch] Carolos Livadas and Nancy A. Lynch. A Reliable Broadcast Scheme for Sensor Networks. Technical Report 915, MIT Computer Science and Artificial Intelligence Laboratory, Cambridge, MA, February 2007 (Revision of earlier version dated August 2003).

[LMN-tr] Nancy Lynch, Sayan Mitra, and Tina Nolte. Motion coordination using virtual nodes. Tehnical Report MIT-LCS-TR-986, Computer Science and Artificial Intelligence aboratory, Massachusetts Institute of Technology, Cambridge, MA, April 2005.

[LMN] Nancy Lynch, Sayan Mitra, and Tina Nolte. Motion Coordination Using Virtual Nodes. CDC-ECC 2005: Forty-Fourth IEEE Conference on Decision and Control, and European Control Conference, Seville, Spain, December 2005. Invited paper.

[RAMBOI] Nancy Lynch and Alex Shvartsman. RAMBO: A Reconfigurable Atomic Memory Service for Dynamic Networks. In D. Malkhi, editor, Distributed Computing (Proceedings of the 16th International Symposium on DIStributed Computing (DISC) October 2002, Toulouse, France), volume 2508 of Lecture Notes in Computer Science, pages 173-190, 2002. Springer-Verlag. Also, Technical Report MIT Laboratory for Computer Science, Technical Report MIT-LCS-TR-856, Cambridge, MA, 2002.

[LSV-concur] Nancy Lynch, Roberto Segala, and Frits Vaandrager. Compositionality for Probabilistic Automata. In Roberto Amadio and Denis Lugiez, editors, CONCUR 2003 - Concurrency Theory (14th International Conference on Concurrency Theory, Marseille, France, September, 2003), volume 2761 of Lecture Notes in Computer Science, pages 208-221, Springer-Verlag, 2003. Also, long version as Technical Report MIT-LCS-TR-907, MIT Laboratory for Computer Science, Cambridge, MA, and submitted for journal publication.

[MR04] Sayan Mitra and Jesse Rabek. Energy Efficient Connected Clusters for Mobile Ad Hoc Networks. MED-HOC-NET 2004, Third Annual Mediterranean Ad Hoc Networking Workshop, Bodrum, Turkey, June 2004.

[MitraLiberzon] Sayan Mitra and Daniel Liberzon. Stability of Hybrid Automata with Average Dwell Time: An Invariant Approach. Proceedings of the 43rd Conference on Decision and Control, Paradise Island, Bahamas, December, 2004.

[Tauber] Joshua A. Tauber. Verifiable Compilation of I/O Automata without Global Synchronization. PhD Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA 02139, February, 2005.

[TauberLT] Joshua A. Tauber and Nancy A. Lynch and Michael J. Tsai. Compiling IOA without Global Synchronization. Proceedings of the 3rd IEEE International Symposium on Network Computing and Applications (IEEE NCA04), Cambridge, MA, August 2004.

[TauberGarland] Joshua A. Tauber and Stephen J. Garland. Definition and Expansion of Composite Automata in IOA. MIT CSAIL Technical Report MIT-LCS-TR-959, July 2004.

[VTTL] Mandana Vaziri, Joshua A. Tauber, Michael J. Tsai, and Nancy Lynch. Systematic Removal of Nondeterminism for Code Generation in I/O Automata. MIT CSAIL Technical Report MIT-LCS-TR-960, July 2004.

[J1] T. Henzinger, B. Horowitz, and C. Kirsch. Giotto: A time-triggered language for embedded programming. Proceedings of the IEEE, volume 91, 2003.

[J2] T. Henzinger, C. Kirsch, M. Sanvido, and W. Pree. From control models to real-time code using Giotto. IEEE Control Systems Magazine, volume 23, number 1, 2003.

[J3] R. Alur, T. Henzinger, G. Lafferriere, and G. Pappas. Discrete Abstractions of Hybrid Systems. Proceedings of the IEEE, volume 88, 2000.

[J4] T. Henzinger, J. Raskin, and R. Majumdar. A Classification of Symbolic Transition Systems. ACM Transactions on Computational Logic, volume 6, 2005.

[J5] J. Raskin, P. Schobbens, and T. Henzinger. Axioms for real-timelogics. Theoretical Computer Science, volume 274, 2002.

[C1] T. Henzinger, B. Horowitz, and C. Kirsch. Giotto: A Time-Triggered Language for Embedded Programming. ACM Conference on Embedded Software, 2001.

[C2] T. Henzinger and C. Kirsch, The Embedded Machine: Predictable,Portable Real-Time Code. ACM Conference on Programming Language Design and Implementation, 2002.

[C3] T. Henzinger, B. Horowitz, and C. Kirsch. Embedded ControlSystems Development with Giotto. ACM Conference on Languages, Compilers, and Tools for Embedded Systems, 2001.

[C4] T. Henzinger, C. Kirsch, R. Majumdar, and S. Matic. Time-safety checking for embedded programs. ACM Conference on Embedded Software, 2002.

[C5] C. Kirsch, M. Sanvido, T. Henzinger, and W. Pree. A Giotto-based helicopter control system. ACM Conference on Embedded Software, 2002.

[C6] T. Henzinger, C. Kirsch, and S. Matic. Schedule Carrying Code. ACM Conference on Embedded Software, 2003.

[C7] A. Ghosal, T. Henzinger, C. Kirsch, and M. Sanvido. Event-driven Programming with Logical Exceution Times. Workshop on Hybrid Systems: Computation and Control (HSCC), 2004.

[C8] T. Henzinger and C. Kirsch. A Typed Assembly Language for Real-Time Programs. ACM Conference on Embedded Software, 2004.

[C9] L. de Alfaro and T. Henzinger. Interface Automata. ACMSymposium on Foundations of Software Engineering, 2001.

[C10] L. de Alfaro, T. Henzinger, and M. Stoelinga. Timed interfaces. ACM Conference on Embedded Software, 2002.

[C11] L. de Alfaro, M. Faella, T. Henzinger, R. Majumdar, and M. Stoelinga. The Element of Surprise in Timed Games. Conference onConcurrency Theory, 2003.

[C12] L. de Alfaro and T. Henzinger. Concurrent Omega-Regular Games. IEEE Symposium on Logic in Computer Science, 2000.

[C13] L. de Alfaro and T. Henzinger. Interface Theories for Component-based Besign. ACM Conference on Embedded Software, 2001.

[C14] L. de Alfaro, T. Henzinger, and R. Jhala. Compositional Methods for Probabilistic Systems. Conference on Concurrency Theory, 2001.

[C15] T. Henzinger. The Theory of Hybrid Automata. Verification of Digital and Hybrid Systems, NATO ASI Series F: Computer and Systems Sciences, volume 170, Springer, 2000.

[C16] T. Henzinger, M. Minea, and V. Prabhu. Assume-Guarantee Reasoning for Hierarchical Hybrid Systems. Workshop on Hybrid Systems: Computation and Control, 2001.

[C17] T. Henzinger, J. Preussig, and H. Wong-Toi. Some Lessons from the HyTech Experience. Conference on Decision and Control, 2001.

[C18] T. Henzinger, Masaccio: A Formal Model for Embedded Components. Conference on Theoretical Computer Science, 2000.

[C19] F. Cassez, T. Henzinger, and J. Raskin. A Comparison of Control Problems for Timed and Hybrid Systems. Conference on Hybrid Systems: Computation and Control, 2002.

[C20] L. de Alfaro, M. Faella, T. Henzinger, R. Majumdar, and M. Stoelinga. Model Checking Discounted Temporal Properties. Conference on Tools and Algorithms for the Construction and Analysis of Systems, 2004.

Appendix I: Honors, Awards and Press Releases

- Avideh Zakhor received Okawa Foundation Prize 2004 on wireless video communication.
- Avideh Zakhor was appointed Fellow of IEEE, 2002.
- Best paper award: T. Nguyen and A. Zakhor, "Distributed Video Streaming with Forward Error Correction" in Packet Video 2002, Pittsburgh, April 2002.
- Minghua Chen of UC Berkeley received the Eli Juri Award in 2007 for his thesis which was sponsored by this MURI.
- Kishor S. Trivedi was awarded Fulbright Fellowship from Nov. 2002-June 2003 and was Poonam and Prabhu Goel Chair Professor at IIT Kanpur during his Sabbatical from Duke University.
- Mostafa Ammar was elected ACM FELLOW in December 2003.
- Paul Judge (MURI Fellow who graduated in Dec. 2002) was named to MIT Technology Review's Magazine top 100 young innovators in 2003.
- Kang G. Shin received the following honors and awards:
    - Stephen Attwood Award, College of Engineering, The University of Michigan (the highest award/honor in the college) (2004).
    - Outstanding Zhukezhen Lectureship Award (2004).
    - IEEE RTC Technical Achievement Award (2003).
    - Best IBM Research Papers in Computer Science, Electrical Engineering and Math published in 2002 (2003).
    - IEEE IWQoS Best Paper Award
    - 2003 IEEE Communications Society William R. Bennett Prize Paper Award.
    - Distinguished Alumni Award from College of Engineering of Seoul National University (2002).
- Nancy Lynch received the following honors and awards:
    - Knuth prize (2007)
    - Van Wijngaarden prize (2006)
    - Technology Review's ``10 Emerging Technologies That Will Change the World" (2003)
    - Elected to National Academy of Engineering (2001)
    - Dijkstra Prize/PODC Influential Paper Award, for ``Impossibility of Consensus with one Faulty Process", with Fischer and Paterson (2001)
- Idit Keidar received the following honors and awards:
    - Alon Fellowship for Junior Faculty (2001)
    - Awarded a Technion Management Career Development Chair (2001)
- Alex Shvartsman received the following honors and awards:
    - Outstanding Research Award for Junior Faculty at the University of Connecticut (2001)
    - Recepient of the NSF CAREER Award for 2000-2004
- Roger Khazan was elected to Sigma Xi, The Scientific Research Society (2001)
- Michael Tsai received the Anna Pogosyants UROP Award (2000)
- Rui Fan (with N. Lynch) received the Best Student Paper award, PODC 2004 and Best Student Paper award, PODC 2006

- Seth Gilbert et al: DISC 2003 paper on Geoquorums invited for special journal issue (2003)
- Gregory Chockler received the following honors and awards:
    - Active Disk Paxos paper was invited to a special issue of Distributed Computing (2002)
    - Best paper and best student paper in Middleware 2000 (2000)
- Panayiotis Mavrommatis received Honorable Mention from the Computing Research Association, for his work on implementing a code generator for IOA specifications of distributed algorithms (2005)
- Calvin Newport published book ``How to Win at College: Surprising Secrets for Success from the Country's Top Students" (2005)

Appendix II: Technology Transitions

- Minghua Chen transitioned his E-MULTFRC results to Caltech group headed by Professor Stephen Low.
- Minghua Chen's E-MULTFRC results were implemented on actual Brew phones to demonstrate effectiveness on CDMA 1XRTT and EVDO networks. Throughput increase of up to 50% was observed.
- Web based Dropping/Blocking Probability Calculator is available on PI Trivedi's webpage: www.ee.duke.edu/~kst
- PI Trevedi's collaborations with Prof. Dohi of Hiroshima University, Prof. Bobbio of Alexandria (Italy), Prof. Jalote of IIT Kanpur was at various levels: co-authored several papers and a jointly supervised Ph.D. Student (Vibhu Sharma).
- PI Trevedi collaborated with IBM to implement software rejuvenation in their xSeries systems. This work with IBM is one of the fastest technology transfers our research group has done. IBM, Sun and Motorola have supported several summer internships in this area. We have proposed to Motorola to implement our ideas in their Cable Modem Termination System. One Ph.D. dissertation (Kalyan Vaidyanathan's) supported in part by this grant has been completed on this topic. Sun Microsystems is continuing to take this research forward. One patent on this topic jointly with Kenny Gross of Sun Microsystems has been granted.
- K. Vaidyanathan Graduated in Nov. 2002 and joined Sun Microsystems.
- Dongyan Chen Graduated in March 2003 and joined Mitsubishi Electronic Research Lab.
- S. Dharmaraja first moved to TRLabs, Winnipeg, Canada and then joined as an Assistant Professor, Dept. of Mathematics, I.I.T. Delhi, India.
- X. Ma joined as faculty, the Oral Robertson Univ.
- Y. Cao graduated and joined OPNET Technologies.
- W. Xie graduated and joined AT & T.
- PI Ammar's efforts in the Message Ferrying work ultimately seeded a much larger effort in the area of Disruption Tolerant Networks. This work is now funded by contracts with DARPA as well as NSF.
- PI Shin contributed our results via an industry partner, Philips Research USA, to IEEE 802.11 Standards Working Groups.
- Transitions by MIT:

  Customer: University of Connecticut
  Contact: Dr. Alex Shvartsman
  Results: Our work on the Rambo algorithms for reconfigurable atomic memory in dynamic networks.
  Applications: Continued this work by producing several engineering improvements on the algorithm and implementing the results in a LAN. Work involved Peter Musial, Vincent Gramoli, Chryssis Georgiou, and others.
  Keyword: Theory

  Customer: Hewlett-Packard
  Contact: Jeannie R. Albrecht, Yasushi Saito

Results: Our work on Rambo algorithms for reconfigurable atomic memory in dynamic networks.
Applications: Continued this work with the intention of using it in HP systems. Wrote the paper ``Rambo for Dummies''.
Keyword: Concept

Customer: IRISA/INRIA
Contact: Dr. Vincent Gramoli
Results: Rambo algorithms.
Applications: New ideas on using reconfigurable quorum systems in peer-to-peer systems. For example: Peer-to-peer Architecture for Self Atomic Memory; SQUARE: Scalable Quorum-Based Atomic Memory with Local Reconfiguration These were outgrowths of Gramoli's work with Alex Shvartsman and ourselves on Rambo.
Keyword: Theory

Customer: SUNY Buffalo
Contact: Dr. Murat Demirbas
Results: Our collision detector models and results.
Applications: Generalized and implemented MAC layer protocols based on our collision detector results. For example: ROBCAST: A Reliable MAC Layer Protocol for Broadcast in Wireless Sensor Networks; A MAC Layer Protocol for Priority-based Reliable Multicast in Wireless Ad Hoc Networks; A Transactional Framework for Programming Wireless Sensor/Actor Networks. These were direct outgrowths of our work with Murat on wireless networks.
Keyword: Concept, Methodology

Customer: Systems research community
Results: Our theoretical treatment of Brewer's Conjecture.
Applications: This work is frequently cited in the systems literature in the context of motivation for understanding data consistency models that are weaker than atomicity.
Keyword: Theory

Customer: Ben-Gurion University
Contact: Dr. Shlomi Dolev
Results: Our work on Geoquorums.
Applications: As a direct follow-up on our work on Geoquorums, Dolev and co-workers designed new, improved quorum systems for use with a geography-aware mobile network. For example: Geographic Quorum System Approximations.
Keyword: Theory, Concept

Customer: Texas A&M U.
Contact: Dr. Jennifer Welch
Results: Geoquorums.
Applications: As a follow-up to our work on Geoquorums, Chen and Welch developed new uses of network density to facilitate computation in mobile networks. For example: Location-based broadcasting for dense mobile ad hoc networks.
Keyword: Theory, Concept

Customer: Lincoln Laboratories
Contact: Dr. Roger Khazan
Results: Our work on group communication system design.

Applications: Used our work on group communication system design to develop a ``chat" system for use by the Air Force.
Keyword: Concept, Methodology

Customer: Lincoln Laboratories
Contact: Dr. Roger Khazan
Results: Our work on group communication and on analysis of security protocols.
Applications: As an outgrowth of our work on group communication and on analysis of security protocols, Dr. Khazan worked with us to develop practical group key management schemes, and to use these schemes to develop new secure group communication applications.
Keyword: Concept

Customer: ETH Zurich
Contact: Dr. Roger Wattenhofer
Results: Our lower bound result for gradient clock synchronization.
Applications: Meier and Thiele extended our lower bound result for gradient clock synchronization to obtain a better bound, for a more restrictive class of ``oblivious" algorithms. Locher and Wattenhofer extended our results by obtaining a nontrivial upper bound for gradient clock synchronization.
Keyword: Theory

Customer: Microsoft Research Asia
Contact: Dr. Wei Chen
Results: Our brand-new results on weakest failure detectors (by Guerraoui, Kouznetsov, Lynch, and Newport).
Applications: Already extending our results to different classes of detectors and to obtain sharper results.
Keyword: Theory

Customer: VeroModo, Inc.
Contact: Dr. Alex Shvartsman
Results: Our basic TIOA modeling work.
Applications: Transitioning our basic TIOA modeling work so that it can be used by practical communication system and hybrid system designers, as well as by teachers and distributed systems researchers.
Keyword: Theory, Methodology

Customer: Naval Research Laboratory
Contact: Dr. Myla Archer
Results: Our Tempo/TIOA language.
Applications: Used our Tempo/TIOA language as a basis for developing new tools for system verification, using PVS and the NRL-developed TAME interface.
Keyword: Theory, Concept, Methodology, Code

Customer: Cisco Systems
Contact: Dr. Ralph Droms
Results: Our TIOA language and modeling tools, plus our techniques for decomposing and analyzing distributed algorithms.
Applications: Joint work with ourselves, funded by Cisco, applied our TIOA language and modeling tools, plus our techniques for decomposing and analyzing distributed

algorithms, to analyze the correctness and performance of the DHCP communication protocol.
Keyword: Methodology

Customer: Lehman College, CUNY
Contact: Dr. Nancy Griffeth
Results: Our Tempo/TIOA language and tools.
Applications: Using our Tempo/TIOA language and tools in teaching courses on network protocols and distributed algorithms. Also using Tempo in research in network testing and automatic protocol generation.
Keyword: Theory, Concept, Methodology, Code

Customer: NASA Langley
Contact: Dr. Cesar Munoz
Results: We modeled and analyzed the SATS landing protocol, which was developed by NASA.
Applications: We are working this summer on extending the analysis to additional NASA flight control protocols.
Keyword: Methodology

Customer: Stony Brook U.
Contact: Dr. Scott Smolka
Results: Tempo/TIOA
Applications: Using Tempo/TIOA in modeling and analyzing biological systems involving heart muscle cells. Also, constructing a model-checker using TIOA.
Keyword: Methodology, Code

Customer: Radboud University, Nijmegen
Contact: Dr. Frits Vaandrager
Results: TIOA and the related model HIOA.
Applications: Has used TIOA and the related model HIOA as the basis for many system modeling and analysis case study projects. Currently using TIOA as a basis for a new proposed project on formal methods for distributed system modeling and analysis.
Keyword: Theory, Concept, Methodology, Code

Customer: American University, Beirut
Contact: Dr. Paul Attie
Results: Tempo/TIOA
Applications: Using Tempo/TIOA as a vehicle for developing and implementing new abstraction techniques for analyzing safety and liveness properties of distributed systems.
Keyword: Theory, Concept, Methodology, Code

Customer: Universite catholique de Louvain, Belgium
Contact: Dr. Olivier Pereira
Results: Our security protocol modeling framework and analysis techniques.
Applications: Used our security protocol modeling framework and analysis techniques to perform computational security analysis of electronic voting protocols.
Keyword: Theory, Concept, Methodology

Customer: NTT Communication Science Laboratories, Japan.
Contact: Dr. Tadashi Arargi

Results: Our foundational model to develop automated verification techniques for security protocols.
Applications: Used our foundational model to develop automated verification techniques for security protocols.
Keyword: Theory, Concept, Methodology

Customer: Vanderbilt University
Contact: James Hill
Results: Our Tempo/TIOA tools.
Applications: Using the tools in developing his own modeling and analysis tools, for large-scale distributed system applications.

Appendix III: Patents and Inventions

1. Methods and systems for determining an optimal training interval in a communications system, US 7,092,437 B2, filed on April 25, 2003; granted on August 15, 2006; Kishor Trivedi with Dongyan Chen.
2. Methods and systems for improving utilization of traffic channels in a mobile communications network, US 7,099,672, filed on February 6, 2002; granted on August 29, 2006, Kishor Trivedi with Xiaomin Ma and Yun Liu.
3. Method and apparatus for using pattern-recognition to trigger software rejuvenation, 7,100,079, filed on October 22, 2002; granted on August 29, 2006; Kishor Trivedi with Kenny Gross.
4. Model-Based Software Design and Validation by Stephen J. Garland and Nancy A. Lynch. US 6,289,502 B1, September 11, 2001
5. Optimization of Streaming Data Throughput in Unreliable Networks by Minghua Chen and Avideh Zakhor.

Appendix IV: Personnel

Principal Investigators

Avideh Zakhor, (UC Berkeley)
Thomas Henzinger (UC Berkeley)
Kishor S. Trevedi (Duke)
Mostafa Ammar (Georgia Tech)
Kang G. Shin (Univ of Michigan)
Nancy Lynch (MIT)

Postdoctoral Researchers

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Luca de Alfaro, postdoc
Christoph Kirsch, postdoc
Marco Sanvido, postdoc
Xiaomin Ma, postdoc
S. Dharmaraja, postdoc
Y. Hong, postdoc
Idit Keidar, postdoc

Graduate Students

Wei Wei, PhD
Minghua Chen, PhD
Pierre Garrigue, MS
Thinh Ngyuen, PhD
Puneet Mehra. MS
Matulya Bansal, MS
Arkadeb Ghosal, PhD
Benjamin Horowitz, PhD
Ranjit Jhala, PhD
Rupak Majumdar, PhD
Slobodan Matic, PhD
Vinayak Prabhu, PhD
Kalyan Vaidyanathan, PhD
Dongyan Chen, PhD
Y. Cao, PhD
W. Xie, PhD
Paul Judge, PhD
Li Zou, PhD
Minaxi Gupta, PhD
Taehyun Kim, PhD
Meng Guo, PhD
Wenrui Zhao, PhD
Daji Qiao, PhD
Haining Wang, PhD
Chun-Ting Chou, PhD
Mohamed El-Gendy, PhD
Gregory Chockler, PhD
Carl Livadas, PhD
Seth Gilbert, PhD Student
Tina Nolte, PhD Student
Rui Fan, PhD Student
Calvin Newport, PhD Student

Appendix V: Publications

BOOK CHAPTERS (Total: 1)

W. Wei and A. Zakhor, "Multipath Unicast and Multicast Video Communication over Wireless Ad Hoc Networks" to appear in Broadband Mobile Multimedia: Techniques and Applications, Auerbach Publications, CRC Press, edited by Yan Zhang, Shiwen Mao, Laurence T. Yang, and Thomas M. Chen, 2007.

PEER-REVIEWED JOURNALS (Total: 72)

1. W. Wei and A. Zakhor, "Multiple Tree Video Multicast over Wireless Ad Hoc Networks," IEEE Transactions on Circuits, Systems and Video Technology, Vol. 17, No. 1, Jan. 2007, pp. 2-15.
2. M. Chen and A. Zakhor, "Multiple TFRC Connections Based Rate Control for Wireless Networks," IEEE Trans. on Multimedia, Vol. 8 , No. 5, Oct. 2006, pp. 1045-1062.
3. S. H. Kang and A. Zakhor, "Effective Bandwidth Based Scheduling for Streaming Multimedia", IEEE Transactions on Multimedia, Vol. 7, No. 6, December 2005, pp. 1139-1148.
4. M. Chen and A. Zakhor, "Rate Control for Streaming Video over Wireless", IEEE Wireless Communications, Vol. 12, Issue 4, Aug. 2005, pp. 32-41 (invited paper).
5. P. Mehra, C. D. Vleeschouwer, and A. Zakhor, "Receiver-Driven Bandwidth Sharing for TCP and its Application to Video Streaming", IEEE Transactions on Multimedia, Vol. 7, No. 4, August 2005, pp. 740-752.
6. T. Nguyen and A. Zakhor, "Multiple Sender Distributed Video Streaming" in IEEE Transactions on Multimedia, Vol. 6, No. 2, April 2004, pp. 315 - 326.
7. X. Tang and A. Zakhor, "Matching Pursuit Multiple Description Coding for Wireless Video", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 12, No. 6, June 2002, pp. 566-575.
8. W. Tan and A. Zakhor, "Video Multicast using Layered FEC and Scalable Compression" in IEEE Transactions on Circuits and Systems for Video Technology, March 2001, Vol. 11, No. 3, pp. 373-386.
9. R. Neff and A. Zakhor, "Matching Pursuit Video Coding - Part 1: Dictionary Approximation", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 12, No. 1, January 2002, pp. 13-26.
10. R. Neff and A. Zakhor, "Matching Pursuit Video Coding - Part 2: Operational Models for Rate and Distortion", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 12, No. 1, January 2002, pp. 27-39.
11. C. De Vleeschouwer and A. Zakhor, "In loop atom modulus quantization for matching pursuit and its applications to video coding" in IEEE Transactions on Image Processing, Vol. 12, No. 10, October 2003, pp. 1226 - 1242.
12. T. Henzinger, B. Horowitz, and C. Kirsch. Giotto: A time-triggered language for embedded programming. Proceedings of the IEEE, volume 91, 2003.
13. T. Henzinger, C. Kirsch, M. Sanvido, and W. Pree. From control models to real-time code using Giotto. IEEE Control Systems Magazine, volume 23, number 1, 2003.

14. R. Alur, T. Henzinger, G. Lafferriere, and G. Pappas. Discrete Abstractions of Hybrid Systems. Proceedings of the IEEE, volume 88, 2000.
15. T. Henzinger, J. Raskin, and R. Majumdar. A Classification of Symbolic Transition Systems. ACM Transactions on Computational Logic, volume 6, 2005.
16. J. Raskin, P. Schobbens, and T. Henzinger. Axioms for real-time logics. Theoretical Computer Science, volume 274, 2002.
17. S. Dharmaraja, Kishor S. Trivedi and Dimitris Logothetis, "Performance Analysis of Cellular Networks with Generally Distributed Handoff Interarrival Times", Computer Communications, pp. 1747-1755, vol. 26, 2003.
18. 2. Kishor S. Trivedi, Dharmaraja Selvamuthu, and Xiaomin Ma, "Analytic Modeling of Handoffs in Wireless Cellular Networks", Information Sciences, 148, 155-166, 2002.
19. D.-Y. Chen, Y. Hong and K. S. Trivedi, "Optimal estimation of training interval for channel equalizations," *IEEE Transactions on Wireless Communications*, Vol. 3, No. 5, Sept. 2004.
20. D.-Y. Chen, Y. Hong, Y. Cao and K. S. Trivedi, "Preventive maintenance of system with phase-type failure time distribution and non-zero inspection time," *International Journal of Quality and Safety Engineering*, Vol. 10, No. 3, pp. 323-344, September 2003.
21. D. Chen, K.S. Trivedi, "Closed-form analytical results for condition-based maintenance", *Reliability Engineering & System Safety*, pp. 43-51, Vol. 76(1), 2002.
22. Xiaomin Ma, Yonghuan Cao, Yun Liu, and K. S. Trivedi, "Modeling and performance analysis for soft handoff schemes in CDMA cellular systems," *IEEE Transactions on Vehicular Technology,* 55(2), March 2006.
23. Xiaomin Ma, Yun Liu, and K. S. Trivedi, "Design and analysis of a new soft handoff scheme for CDMA cellular system" *IEEE Transactions on Vehicular Technology,* 55(5), September 2006.
24. K. S. Trivedi, Xiaomin Ma, and S. Dharmarja, "Performability modeling of wireless communication systems," *International Journal of Communication Systems*, 16(6), 561-577, Aug. 2003.
25. B. B. Madan, S. Dharmaraja and K. S. Trivedi, "Combined guard channel and mobile assisted handoff for cellular networks," to be published in *IEEE Transactions on Vehicular Technology,* 2008.
26. K. Vaidyanathan and K.S. Trivedi, "A Comprehensive Model for Software Rejuvenation", IEEE Trans. on Dependable and Secure Computing, Vol 2, No. 2, April-June 2005.
27. W. Xie, Y. Hong, and K. Trivedi. "Analysis of a two-level software rejuvenation policy," International Journal on Reliability Engineering and System Safety, October 2003.
28. Minaxi Gupta, Mostafa Ammar, Mustaque Ahamad, "Trade-offs between reliability and overhead in peer-to-peer reputation tracking," Computer Networks: The International Journal of Computer and Telecommunications Networking archive Volume 50 , Issue 4 (March 2006)
29. Taehyun Kim, Mostafa Ammar, "A Comparison of Heterogeneous Video Multicast Schemes: Layered Encoding or Stream Replication?" IEEE Transactions on Multimedia Vol 7, 6, Dec. 2005, pp 1123- 1130

30. Taehyun Kim and Mostafa H. Ammar, "Optimal Quality Adaptation for Scalable Encoded Video," IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, Februar Paul Judge, Mostafa Ammar, "Security Issues and Solutions in Multicast Content Distribution: A Survey," y 2005, IEEE Network Magazine, 2003.
31. Paul Judge, Mostafa Ammar, "WHIM: Watermarking Multicast Video with a Hierarchy of Intermediaries,"_Computer Networks 39(6): 699-712 (2002)
32. Chun-Ting Chou and Kang G. Shin, ``Enhancement of TCP throughput on smooth handoffs in MobileIP networks," ACM Wireless Networks (WINET), vol. 13, no. 3 June 2007(in press).
33. Chansu Yu, Kang G. Shin, and Lubo Song, ``Maximizing communication concurrency via link-layer packet salvaging in mobile ad hoc networks," IEEE Trans. on Mobile Computing, vol. 6, no. 4, pp. 449-462, April 2007.
34. Chun-Ting Chou, Sai Shankar N, Hyoil Kim, and Kang G. Shin, ``What and how much to gain by spectral agility," IEEE J. Special Area of Communications, vol. 25, no. 3, pp. 576-588, April 2007.
35. Haining Wang, Cheng Jin, and Kang G. Shin, ``Defense against spoofed IP traffic using hop-count filtering," IEEE/ACM Transactions on Networking, vol. 15, no.1, pp. 40-53, Feb. 2007.
36. Chun-Ting Chou, Kang G. Shin, and Sai Shankar N, ``Distributed control of airtime usage in multirate wireless LANs," IEEE/ACM Transactions on Networking, vol. 14, no. 6, pp. 1179-1192, December 2006.
37. Haining Wang, Abhijit Bose, Mohamed El-Gendy, and Kang G. Shin, ``IP Easy-pass: Edge resource access control," IEEE/ACM Transactions on Networking, vol. 13, no. 6, pp. 1247-1260, December 2005.
38. Chun-Ting Chou and Kang G. Shin, ``An enhanced Inter-Access Point Protocol for uniform intra- and inter-subnet handoffs," IEEE Transactions on Mobile Computing, vol. 4, no. 4, pp. 321-334, July/August 2005.
39. Haining Wang, Danlu Zhang, and Kang G. Shin, ``A change-point monitoring for detection of DoS attacks," IEEE Trans. on Dependable and Secure Computing, vol. 1, no. 4, pp. 193-208, October-December 2004.
40. Haining Wang and Kang G. Shin,``Robust TCP congestion recovery," Journal of High Speed Networks, vol. 13, no. 2, September 2004.
41. Chansoo Yu, Kang G. Shin, and Ben Lee, ``Power-stepped protocol: A novel way of enhancing spatial utilization in a clustered mobile ad hoc network," IEEE Journal of Special Areas of Communications Special Issue on Quality of Service Delivery in Variable topology Networks, vol. 22, no. 7, pp. 1322-1334, September 2004.
42. Chun-Ting Chou and Kang G. Shin, ``Analysis of adaptive bandwidth allocation in wireless networks with multi-level degradable quality of service," IEEE Trans. on Mobile Computing, vol. 3, no. 1, pp. 5-17, Jan.-Mar. 2004.
43. Haining Wang and Kang G. Shin, ``Transport-aware IP routers: a built-in mechanism to counter DDoS attacks," IEEE Trans.~on Parallel and Distributed Systems, vol. 14, no. 9, pp. 873--884, September 2003.
44. Mohamed El-Gendy, Abhijit Bose, and Kang G. Shin, ``Evolution of the Internet QoS and support for soft real-time applications," IEEE Proceedings, vol. 91, no. 7, pp. 1086-1104, July 2003 (invited).

45. D. Qiao, S. Choi, A. Soomro, and K.G. Shin, ``Energy-efficient PCF operation of IEEE 802.11a WLANs via transmit power control," Computer Networks (ComNet), vol. 42, no. 1, May 2003.
46. Daji Qiao, Sunghyun Choi, and Kang G. Shin, ``Goodput analysis and link adaptation for IEEE 802.11a wireless LANs," IEEE Trans. on Mobile Computing, vol. 1, no. 4, pp. 278--292, Oct.-Dec. 2002.
47. Mohamed El-Gendy and Kang G. Shin, ``Assured forward fairness using equation-based marking," Computer Networks, vol. 41, no. 4, pp. 435-450, October 2002.
48. Sunghyun Choi and Kang G. Shin, ``Adaptive bandwidth reservation and admission control in QoS-sensitive cellular networks," IEEE Trans. on Parallel and Distributed Systems, vol. 13, no. 9, pp. 882-897, September 2002.
49. P.C. Attie, A. Arora, and E.A. Emerson. ACM Transactions on Programming Languages and Systems (TOPLAS), vol. 26, no. 1, pp 125-185, January 2004
50. P. C. Attie. Wait-free Byzantine Consensus. Information Processing Letters, vol. 83, no. 4, pp. 221-227, August 2002.
51. P.C. Attie and E.A. Emerson. Synthesis of concurrent systems for an atomic read/write model of computation. ACM Transactions on Programming Languages and Systems, vol. 23, no. 2, pp. 187-242, March 2001.
52. Elizabeth Borowsky, Eli Gafni, Nancy Lynch, and Sergio Rajsbaum. The BG Distributed Simulation Algorithm. Distributed Computing, 14:127-146, 2001.
53. Ling Cheung, Nancy Lynch, Roberto Segala, and Frits Vaandrager. Switched Probabilistic PIOA: Parallel Composition via Distributed Scheduling. Theoretical Computer Science, volume 365, issues 1-2, pages 83-108, 10 November 2006.
54. Bogdan S. Chlebus, Roberto De Prisco, and Alex A. Shvartsman. Performing tasks on synchronous restartable message-passing processors. Distributed Computing, 14:49-64, 2001.
55. Gregory V. Chockler, Idit Keidar, and Roman Vitenberg. Group Communication Specifications: A Comprehensive Study. ACM Computing Surveys, 33(4):1-43, December 2001.
56. Ran Canetti, Ling Cheung, Dilsun Kaynar, Moses Liskov, Nancy Lynch, Olivier Pereira, and Roberto Segala. Using Probabilistic I/O Automata to Improve the Analysis of Cryptographic Protocols. In ERCIM News, 63: 40-41, October 2005.
57. Gregory Chockler and Dahlia Malkhi. Active Disk Paxos with infinitely many processes. Distributed Computing, volume 18, number 1, pages 73-84, July 2005.
58. Constantinos Djouvas, Nancy D. Griffeth, and Nancy A. Lynch. Testing Self-Similar Networks MBT 2006: Second Workshop on Model Based Testing, Electronic Notes in Theoretical Computer Science, issue 4, volume 164, March 2006.
59. Shlomi Dolev, Seth Gilbert, Nancy A. Lynch, Alex A. Shvartsman, and Jennifer L. Welch. GeoQuorums: Implementing Atomic Memory in Mobile Ad Hoc Networks. Distributed Computing, Special Issue DISC03, 18(2):125-155, 2005. Also, Technical Report MIT-LCS-TR-900a, CSAIL, Massachusetts Institute of Technology, Cambridge, MA, 2004.
60. Rui Fan and Nancy Lynch. Gradient Clock Synchronization. Distributed Computing, volume 18, number 4, pages 255-266, March, 2006.

61. Alan Fekete, Nancy Lynch, and Alex Shvartsman. Specifying and Using a Partitionable Group Communication Service. ACM Transactions on Computer Systems, 19(2):171-216, May 2001.
62. Ch. Georgiou, A. Russell and A. Shvartsman. The Complexity of Synchronous Iterative Do-All with Crashes. Distributed Computing, Volume 17, No. 1, pages 47-63, 2004.
63. Ch. Georgiou and A.A. Shvartsman. Cooperative Computing with Fragmentable and Mergeable Groups. Journal of Discrete Algorithms, volume 1 (2), pp. 211-235, 2003.
64. Seth Gilbert and Nancy Lynch. Brewer's conjecture and the feasibility of consistent, available, partition-tolerant web services. Sigact News, 33(2), June 2002.
65. Idit Keidar and Sergio Rajsbaum. A Simple Proof of the Uniform Consensus Synchronous Lower Bound. Information Processing Letters (IPL), 85(1):47-52, January 2003.
66. Idit Keidar, Roger Khazan, Nancy Lynch and Alex Shvartsman. An Inheritance-Based Technique for Building Simulation Proofs Incrementally. ACM Transactions on Software Engineering and Methodology (TOSEM), 11(1):1-29, January 2002. Conference version in ICSE, 2000, pages 478-487.
67. Idit Keidar and Roger Khazan. A virtually synchronous group multicast algorithm for WANs: Formal approach. SIAM Journal on Computing, Vol. 32, No. 1, pp. 78-130, 2002.
68. Carolos Livadas, John Lygeros, and Nancy A. Lynch. High-Level Modeling and Analysis of TCAS. Proceedings of IEEE, Special Issue on Hybrid Systems: Theory & Applications, 88(7):926-948, July 2000.
69. Nancy Lynch. Some Perspectives on PODC. Distributed Computing, 16(1):71-74, 2003.
70. Nancy Lynch, Roberto Segala, and Frits Vaandraager. Hybrid I/O Automata. Information and Computation, 185(1):105-157, August 2003. Also, Technical Report MIT-LCS-TR-827d, MIT Laboratory for Computer Science, Cambridge, MA 02139, January 13, 2003.
71. Sayan Mitra and Myla Archer. PVS Strategies for proving abstraction properties automata. In Electronic Notes in Theoretical Computer Science, volume 125(2), 2005, pages 45-65.
72. Toh Ne Win, Michael Ernst, Stephen Garland, Dilsun Kirli, and Nancy Lynch. Using simulated execution in verifying distributed algorithms. International Journal on Software Tools for Technology Transfer (STTT), 4:(1-10), 2003.

CONFERENCE (Total: 194)

1. A. Zakhor and W. Wei, "Multiple Tree Video Multicast Over Wireless Ad Hoc Networks", International Conference on Image Processing, Atlanta, Georgia, September 2006.
2. W. Wei and A. Zakhor, "Path Selection For Multi-path Streaming in Wireless Ad Hoc Networks", International Conference on Image Processing, Atlanta, Georgia, September 2006.
3. M. Chen and A. Zakhor, "Flow Control over Wireless Network and Application Layer Implementation", Infocom 2006, Barcelona, Spain, April 2006.

4. P. Garrigue and A. Zakhor, "Atom Positioni Coding in a Matching Pursuit Based Video Coder", VLBV workshop, Sardinia, Italy, September 2005, Book Series Lecture Notes in Computer Science, Visual Content Processing and Representation, Springer Berlin / Heidelberg, Volume 3893, 2006, pp. 153 - 160.
5. M. Chen and A. Zakhor, "AIO-TFRC: A light-weighted rate control scheme for streaming over wireless" in IEEE WirelessCom Symposium on Multimedia over Wireless 2005, Maui, Hawaii, June 2005, Vol. 2, pp. 1124 - 1129. (invited paper)
6. M. Bansal and A. Zakhor, "Path Diversity for Overlay Multicast Streaming", Packet Video Workshop, Irvine, CA, Dec. 2004.
7. M. Bansal and A. Zakhor, "Path Diversity Based Techniques for Resilient Overlay Multimedia Multicast", Picture Coding Symposium (PCS) 2004, San Francisco, CA, Dec. 2004. (invited paper)
8. W. Wei and A. Zakhor, "Multipath Unicast and Multicast Video Communication over Wireless Ad Hoc Networks" in International Conference on Broadband Networks (Broadnets) 2004, San Jose, CA, October 2004, pp. 496-505. (invited paper)
9. M. Chen and A. Zakhor, "Transmission Protocols for Streaming Video over Wireless" in International Conference on Image Processing 2004, Singapore, October 2004, pp. 1743-1746. (invited paper)
10. W. Wei and A. Zakhor, "Robust Multipath Source Routing Protocol (RMPSR) for Video Communication over Wireless Ad Hoc Networks" in International Conference on Multimedia and Expo 2004, pp:1379 - 1382, Taipei, Taiwan, June 2004.
11. W. Wei and A. Zakhor, "Connectivity for Multiple Multicast Trees in Ad Hoc Networks" in International Workshop on Wireless Ad-hoc Networks, Oulu, Finland, June 2004, pp. 270-274.
12. M. Chen and A. Zakhor, "Rate Control for Streaming Video over Wireless" in INFOCOM, HongKong, P.R.China, Mar. 2004.
13. S. H. Kang and A. Zakhor, "Effective Bandwidth Based Scheduling for Streaming Multimedia" in International Conference on Image Processing 2003, Barcelona, Spain, Vol. 2, pp. III-633-636, September 2003.
14. S. Cheung and A. Zakhor, "Fast Similarity Search on Video Signatures" in International Conference on Image Processing 2003, Barcelona, Spain, Vol. 3, pp. II-1-4, September 2003.
15. T. Nguyen and A. Zakhor, "Matching Pursuits Based Multiple Description Video Coding for Lossy Environments" in International Conference on Image Processing 2003, Vol. 1, Barcelona, Spain, September 2003, pp.57-60. (invited paper)
16. T. Nguyen, P. Mehra, and A. Zakhor, "Path Diversity and Bandwidth Allocation for Multimedia Streaming" in International Conference on Multimedia and Expo, Vol. 1, Baltimore, Maryland, July 2003, pp. 1-4. (invited paper)
17. P. Mehra and A. Zakhor, "TCP-Based Video Streaming Using Receiver-Driven Bandwidth Sharing" in 132th International Packet Video Workshop, Nantes, France, April 2003.
18. P. Mehra and A. Zakhor, "Receiver-Driven Bandwidth Sharing for TCP" in Proceedings of IEEE INFOCOM 2003, San Francisco, California , April 2003.
19. T. Nguyen and A. Zakhor, "Path Diversity with Forward Error Correction (PDF) System for Packet Switched Networks" in Proceedings of IEEE INFOCOM 2003, San Francisco, California, April 2003.

20. C. D. Vleeschouwer and A. Zakhor, "Atom Modulus Quantization for Matching Pursuits Video Coding" in International Conference on Image Processing 2002, Rochester, New York, September 2002, Vol. 3, p. 681-684.
21. S. Cheung and A. Zakhor, "Efficient Video Similarity Measurement with Video Signature" in International Conference on Image Processing 2002, Rochester, New York, September 2002, Vol. 1, p. 621-624.
22. T. Nguyen and A. Zakhor, "Protocols for Distributed Video Streaming" in International Conference on Image Processing 2002, Rochester, New York, September 2002, Vol. 3, p. 185-189.
23. Y. Shan and A. Zakhor, "Cross Layer Techniques for Adaptive Video Streaming Over Wireless Networks" in International Conference on Multimedia and Expo, Lausanne, Switzerland, August 2002, pp. 277 - 280.
24. S. H. Kang and A. Zakhor, "Packet Scheduling Algorithm for Wireless Video Streaming" in Packet Video 2002, Pittsburgh, April 2002.
25. T. Nguyen and A. Zakhor, "Distributed Video Streaming with Forward Error Correction" in Packet Video 2002, Pittsburgh, April 2002. (Best Paper Award.)
26. T. Nguyen and A. Zakhor, "Distributed video streaming over internet" in Multimedia Computing and Networking 2002, Proceedings of SPIE, San Jose, California, January 2002, Vol. 4673, p. 186-195.
27. S. Cheung and A. Zakhor, "Video similarity detection with video signature clustering" in Proceedings of the International Conference on Image Processing, Thessaloniki, Greece, October 2001, Vol. 2, p. 649-652.
28. X. Tang and A. Zakhor, "Matching pursuits multiple description coding for wireless video" in Proceedings of the International Conference on Image Processing, Thessaloniki, Greece, October 2001, Vol. 1, p. 926-929.
29. W. Tan and A. Zakhor, "Packet classification schemes for streaming MPEG video over delay and loss differentiated networks" in Proceedings of Packet Video Workshop 2001, Kyongju, Korea, April 2001.
30. R. Neff and A. Zakhor, "Dictionary Approximation for Matching Pursuit Video Coding" in Proceedings of the International Conference on Image Processing, Vancouver, Canada, September 2000, Vol. 2, pp. 828-831.
31. S. Cheung and A. Zakhor, ``Efficient Video Similarity Measurement and Search" in Proceedings of the International Conference on Image Processing, Vancouver, Canada, September 2000, Vol. 1, p. 85-89.
32. T. Nguyen and A. Zakhor, ``Performance Analysis of an H.263 Video Encoder for IRAM" in Proceedings of the International Conference on Image Processing, Vancouver, Canada, September 2000, Vol. 3, pp. 98-101.
33. S. Cheung and A. Zakhor, ``Estimation of Web Video Multiplicity," in Proceedings of SPIE Conference on Internet Imaging, San Jose, California, January 2000, Vol. 3964, pp. 34-46.
34. T. Henzinger, B. Horowitz, and C. Kirsch. Giotto: A Time-Triggered Language for Embedded Programming. ACM Conference on Embedded Software, 2001.
35. T. Henzinger and C. Kirsch, The Embedded Machine: Predictable, Portable Real-Time Code. ACM Conference on Programming Language Design and Implementation, 2002.

36. T. Henzinger, B. Horowitz, and C. Kirsch. Embedded Control Systems Development with Giotto. ACM Conference on Languages, Compilers, and Tools for Embedded Systems, 2001.
37. T. Henzinger, C. Kirsch, R. Majumdar, and S. Matic. Time-safety checking for embedded programs. ACM Conference on Embedded Software, 2002.
38. C. Kirsch, M. Sanvido, T. Henzinger, and W. Pree. A Giotto-based helicopter control system. ACM Conference on Embedded Software, 2002.
39. T. Henzinger, C. Kirsch, and S. Matic. Schedule Carrying Code. ACM Conference on Embedded Software, 2003.
40. A. Ghosal, T. Henzinger, C. Kirsch, and M. Sanvido. Event-driven Programming with Logical Exceution Times. Workshop on Hybrid Systems: Computation and Control (HSCC), 2004.
41. T. Henzinger and C. Kirsch. A Typed Assembly Language for Real-Time Programs. ACM Conference on Embedded Software, 2004.
42. L. de Alfaro and T. Henzinger. Interface Automata. ACM Symposium on Foundations of Software Engineering, 2001.
43. L. de Alfaro, T. Henzinger, and M. Stoelinga. Timed interfaces. ACM Conference on Embedded Software, 2002.
44. L. de Alfaro, M. Faella, T. Henzinger, R. Majumdar, and M. Stoelinga. The Element of Surprise in Timed Games. Conference on Concurrency Theory, 2003.
45. L. de Alfaro and T. Henzinger. Concurrent Omega-Regular Games. IEEE Symposium on Logic in Computer Science, 2000.
46. L. de Alfaro and T. Henzinger. Interface Theories for Component-based Besign. ACM Conference on Embedded Software, 2001.
47. L. de Alfaro, T. Henzinger, and R. Jhala. Compositional Methods for Probabilistic Systems. Conference on Concurrency Theory, 2001.
48. T. Henzinger. The Theory of Hybrid Automata. Verification of Digital and Hybrid Systems, NATO ASI Series F: Computer and Systems Sciences, volume 170, Springer, 2000.
49. T. Henzinger, M. Minea, and V. Prabhu. Assume-Guarantee Reasoning for Hierarchical Hybrid Systems. Workshop on Hybrid Systems: Computation and Control, 2001.
50. T. Henzinger, J. Preussig, and H. Wong-Toi. Some Lessons from the HyTech Experience. Conference on Decision and Control, 2001.
51. T. Henzinger, Masaccio: A Formal Model for Embedded Components. Conference on Theoretical Computer Science, 2000.
52. F. Cassez, T. Henzinger, and J. Raskin. A Comparison of Control Problems for Timed and Hybrid Systems. Conference on Hybrid Systems: Computation and Control, 2002.
53. L. de Alfaro, M. Faella, T. Henzinger, R. Majumdar, and M. Stoelinga. Model Checking Discounted Temporal Properties. Conference on Tools and Algorithms for the Construction and Analysis of Systems, 2004.
54. K. S. Trivedi, S. Dharmaraja and X. Ma, "Analytic Modeling of Handoffs in Wireless Cellular Networks", Proc. of 6th Joint Conference on Information Sciences, pp. 1383-1392, March 2002, Raleigh, NC.

55. K. S. Trivedi, X. Ma, "Performability Analysis of Wireless Cellular Networks", Keynote paper, Proc. Symposium on Performance Evaluation of Computer and Telecommunication Systems, SPECTS2002, July 2002, San Diego, CA.
56. D.-Y. Chen, S. Garg and K. S. Trivedi, "Network survivability performance evaluation: A quantitative approach with applications in wireless ad-hoc networks, " MSWiM'02, September, 2002, Atlanta.
57. D.-Y. Chen, S. Garg, M. Kappes and K. S. Trivedi, "Supporting VBR VoIP traffic in IEEE 802.11 WLAN in PCF mode", in OPNETWORK'02, Washington D.C., August 2002.
58. D.-Y. Chen, S. Garg, M. Kappes and K. S. Trivedi, "Supporting VoIP traffic in IEEE 802.11 WLAN with enhanced media access control (MAC) for quality of service," SPECTS'03, July 2003, Montreal, Canada.
59. D.-Y. Chen, S. Garg, C. Kintala and K. S. Trivedi, "Dependability enhancements for wireless local area networks," Int. Symp. Dependable Systems and Networks 2003 (DSN'03), San Franscisco.
60. Y. Liu, K. S. Trivedi, Y. Ma, James J. Han, and H. Levendel , "Modeling and Analysis of Software Rejuvenation in Cable Modem Termination Systems", Proceedings of the 13th Int'l. Symposium on Software Reliability Engineering, ISSRE2002, pp. 159-170, Annapolis, Maryland, November 2002.
61. Y. Hong, D. Chen, and K. S. Trivedi, "Failure mitigation for quality of service of wireless systems," IEEE CDC, December 2002.
62. W. Xie, H. Sun, Y. Cao, and K. Trivedi. Optimal Webserver session timeout settings for Web users. In CMG 2002 Proceedings, volume 2, pages 799–807, Reno, NV, December 2002. Computer Measurement Group (CMG).
63. W. Xie, Y. Hong, and K. S. Trivedi, "Software rejuvenation policies for cluster systems under varying workload", In IEEE Pacific Rim International Symposium on Dependable Computing (PRDC), March, 2004.
64. Xiaomin Ma, Y. Liu, K.S. Trivedi, Y. Ma, and J.J. Han, A new handoff scheme for decreasing both dropping calls and blocking calls in CDMA System, IEEE EURONCON'2001, International Conference on Trends in Communications, p 115-19 vol.1, July 2001.
65. Xiaomin Ma, Y. Liu, K.S. Trivedi, Y. Ma, and J.J. Han, A soft handoff scheme for improving utilization efficiency of traffic channels, IEEE Int. Conf. on CSCC, Greece, July 2001.
66. K. Vaidyanathan, D. Selvamuthu and K.S. Trivedi, "Analysis of Inspection-Based Preventive Maintenance in Operational Software Systems", Proc. of the IEEE Int'l. Symp. on Reliable Distributed Systems, SRDS 2002, Osaka, Japan, October 2002.
67. L. Li, K. Vaidyanathan and K.S. Trivedi, "An Approach to Estimation of Software Aging in a Web Server", Proc. of the Int'l. Symp. on Empirical Software Engineering, ISESE 2002, Nara, Japan, October 2002.
68. W. Xie, H. Sun, Y. Cao, and K. Trivedi. "Modeling of user perceived Webserver availability," In Int. Conf. Communications (ICC), pages 1796–1800, Anchorage, AK, May 2003.
69. ConferencesWenrui Zhao, Mostafa Ammar, Ellen Zegura, "Controlling the Mobility of Multiple Data Transport Ferries in a Delay Tolerant Network," IEEE INFOCOM 2005, April 2005

70. Meng Guo, Mostafa Ammar, Ellen Zegura, "Cooperative Patching: A client based P2P Architecture for supporting continuous live video streaming," Proceedings of the IEEE International Conference on Computers, Communication and Networks (IC3N), Chicago, IL, October 2004.
71. Wenrui Zhao, Mostafa Ammar, Ellen Zegura, "A Message Ferrying Approach for Data Delivery in Sparse Mobile Ad Hoc Networks," Proceedings of ACM Mobihoc 2004, Tokyo Japan, May 2004.
72. Meng Guo, Mostafa Ammar, Scalable Live Video Streaming to cooperative clients using time shifting and video patching," Proceedings of INFOCOM 2004, Hong Kong, Marh 2004.
73. Li Zou, Mostafa Ammar, "A File-Centric Model for Peer-to-Peer File-Sharing Systems," Proceedings of ICNP 2003, Atlanta, GA, Nov. 2003.
74. Minaxi Gupta, Mostafa Ammar, ``Service Differentiation in Peer-to-Peer Networks Utilizing Reputations," Proceedings of the Networked Group Communications (NGC) workshop, October 2003.
75. Paul Judge, Mostafa Ammar, ``CITADEL: A Content protection Architecture for Decentralized Peer-to-Peer Systems," Proceedings of IEEE GLOBECOM 2003, San Francisco, CA, Decemeber 2003.
76. Minaxi Gupta, Paul Judge, Mostafa Ammar, ``A Reputation System for Peer-to-Peer Systems," Proceedings of ACM NOSSDAV 2003, June 2003, Monterey, CA.
77. Wenrui Zhao, Mostafa Ammar, "Message Ferrying: Proactive Routing in Highly-Partitioned Wireless Ad Hoc Networks," Proceedings of the IEEE Workshop on Futrure Trends in Distributed Computing Systems, Puerto Rico, May 2003.
78. Paul Judge, Mostafa Ammar, "The Benefits and Challenges of Providing Content Protection in Peer-to-Peer Systems," International Workshop for Technology, Economy, Social and Legal Aspects of Virtual Goods, May 2003, Ilmenau, Germany.
79. Minaxi Gupta, Mostafa Ammar, "A Novel Multicast Scheduling Scheme for Multimedia Server with Variable Access Patterns," IEEE International Conference on Communications (ICC 2003), Anchorage, Alaska, May 2003.
80. Taehyun Kim, Mostafa Ammar, ``Optimal Quality Adaptation for MPEG-4 Fine-Grained Scalable Video," Proceedings of INFOCOM 2003, April 2003, San Francisco.
81. Paul Judge and Mostafa Ammar, "The role of watermarking in securing peer-to-peer systems," ACM Workshop on Multimedia Security, December 2002.
82. Minaxi Gupta, Mostafa Ammar, "Providing Multicast Communication in a Differentiated Service Network Using Limited Branching Techniques," Proceedings of the Third International Conference on Internet Computing, Las Vegas, Nevada, June 2002. (Full Tech Report Version)
83. Li Zou, Ellen Zegura, Mostafa Ammar, "The Effect of Peer Selection and Buffering Strategies on the Performance of Peer-to-Peer File Sharing Systems," Proceedings of MASCOTS 2002, October 2002.
84. Paul Judge, Mostafa Ammar, "GOTHIC: A Group Access Control Architecture for Secure Multicast and Anycast," Proceedings of INFOCOM 2002, June 2002.
85. Li Zou, Mostafa Ammar, Christoph Diot, " An Evaluation of Grouping Techniques for State Dissemination in Netwokred Multi-User Games" Proceedings of the Ninth

International Symposium on Modelling, Analysis, and Simulation of Computer and Telecommunication Systems, (MASCOTS'01), August 2001

86. Taehyun Kim, Mostafa Ammar, "A Comparison of Layering and Stream Replication Video Multicast Schemes," Proceedings of NOSSDAV 2001, June 2001.
87. Paul Judge, Mostafa Ammar, "WHIM: Watermarking Multicast Video with a Hirarchy of Intermediaries," Proceedings of NOSSDAV 2000, Chapel Hill, NC, June 2000.
88. Daji Qiao and Kang G. Shin, ``Energy-efficient airtime allocation in multi-rate multi-power-level wireless LANs," 2007 IEEE/ACM International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine'07) (in press).
89. Chansoo Yu, Kang G. Shin, Ben Lee, Seung-Min Park, and Heung-Nam Kim, ``Node clustering in mobile peer-to-peer multihop networks," 3rd IEEE International Workshop on Mobile Peer-to-Peer Computing (MP2P'06), March 2006.
90. Mohamed El-Gendy, Kang G. Shin, and Hosam Fathy, ``CONNET: Self-controlled access links for delay and jitter requirements jitter guarantees," (IEEE ICNP'05}, Boston, pp. 332-341, November 2005.
91. Chun-Ting Chou and Kang G. Shin, ``Enhancement of TCP throughput on smooth handoffs in MobileIP networks," 2nd International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks (QShine), Orlando, FL, August 2005.
92. Chansoo Yu, Kang G. Shin, and Lubo Song, ``Link-layer salvaging for making routing progress in mobile ad hoc networks," Proc. ACM MobiHoc'05}, pp. 242-253, May 2005.
93. Daji Qiao and Kang G. Shin, ``Smart Power-Saving Mode for IEEE 802.11 WLANs," Proc. IEEE INFOCOM'05.
94. Chun-Ting Chou, Kang G. Shin, and Sai Shankar, ``Per-stream QoS in the IEEE 802.11 Wireless LAN: An integrated airtime-based admission control and distributed airtime allocation," Proc. IEEE INFOCOM'05.
95. Mohamed El-Gendy, Abhijit Bose, Seong-Taek Park, and Kang G. Shin, ``Paving the first mile for QoS-dependent applications and appliances," Proc. of 12-th IEEE International Workshop on Quality of Service(IWQoS 2004), Montreal, Canada, pp. 245-254, June 2004.
96. Haining Wang, Abhijit Bose, Mohamed El-Gendy, and Kang G. Shin, ``IP Easy-pass: Edge resource access control," IEEE INFOCOM 2004, Hong Kong, March 2004.
97. Cheng Jin, Haining Wang, and Kang G. Shin, ``Hop-count filtering: An effective defense against spoofed DDoS traffic," Tenth ACM Conference on Computer and Communications Security, Washington, DC, pp. 30-41, October 2003.
98. Chun-Ting Chou, Kang G. Shin, and Sai Shankar, ``Inter Frame Space (IFS) based service differentiation for IEEE 802.11e wireless LANs," Proc. 57-th IEEE Vehicle Technology Conference (VTC 2003-Fall), October 2003.
99. Daji Qiao, Sunghyun Choi, Amit Jain, and Kang G. Shin, ``MiSer: an optimal low-energy communication strategy for IEEE 802.11a/h," Proc. ACM MobiCom'03, pp. 161-175, September 16--18, 2003.
100. Amit Jain, Daji Qiao, and Kang G. Shin, ``RT-WLAN: A soft real-time extension to the ORiNOCO Linux device driver," Proc. 14-th IEEE International Symposium

on Personal, Indoor and Mobile Radio Communications (PIMRC'03), September 7-10, Beijing, China.

101. Mohamed El Gendy, Abhijit Bose, Haining Wang, and Kang G. Shin, ``Statistical characterization for per-hop QoS," Proc. 17-th IEEE IWQoS, pp. 21-40, Monterey, CA, June 2003 (Best Paper Award).
102. Daji Qiao, Sunghyun Choi, Amit Jain, and Kang G. Shin, ``Adaptive Transmit Power Control in IEEE 802.11a Wireless LANs," Proc. 57-th IEEE Vehicle Technology Conference (VTC 2003-Spring), Jeju, Korea, April 22-25, 2003.
103. Daji Qiao and Kang G. Shin, ``UMAV: A Simple Enhancement to the IEEE 802.11 DCF," the minitrack on Quality of Service in Mobile and Wireless Networks in the 36-th Hawaii International Conference on System Sciences, Jan. 6-9, 2003.
104. Haining Wang and Kang G. Shin, ``Layer-4 service differentiation and resource isolation," Proc. IEEE RTAS02, San Jose, pp. 67-78, Sep. 2002.
105. Daji Qiao, Sunghyun Choi, Amjad Soomro, and Kang G. Shin, ``Energy-efficient PCF operation of IEEE 802.11a wireless LANs," IEEE INFOCOM 2002, pp. 580-589, New York, June 2002.
106. Haining Wang, Danlu Zhang, and Kang G. Shin, ``Detecting SYN flooding attacks," IEEE INFOCOM 2002, pp. 1530-1539, New York, June 2002.
107. C.-T. Chou and Kang G. Shin, ``Analysis of combined adaptive bandwidth allocation and admission control in wireless networks," IEEE INFOCOM 2002, pp. 676-684, New York, June 2002.
108. Daji Qiao, Kang G. Shin, ``Achieving efficient channel utilization and weighted fairness for data communications in IEEE 802.11 WLAN under the DCF," Proc. of IEEE IWQoS, May 2002.
109. Ittai Abraham, Gregory Chockler, Idit Keidar and Dahlia Malkhi. Byzantine Disk Paxos: Optimal Resilience with Byzantine Shared Memory. Proceedings of the 23rd Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2004), St. John's, Newfoundland, Canada, pages 226-235, July 2004. ACM, (2004).
110. Myla Archer, HongPing Lim, Nancy Lynch, Sayan Mitra and Shinya Umeno. Specifying and Proving Properties of Timed I/O Automata in the TIOA Toolkit. Fourth ACM-IEEE International Conference on Formal Methods and Models for Codesign (MEMOCODE'06), Napa Valley, California, July, 2006.
111. Paul Attie and Hana Chockler. Efficiently Verifiable Conditions for Deadlock-freedom of Large Concurrent Programs. Proceedings of the Sixth International Conference on Verification, Model Checking and Abstract Interpretation, Paris, France, January 2005.
112. Paul Attie, Rachid Guerraoui, Petr Kouznetsov, Nancy Lynch, and Sergio Rajsbaum. The Impossibility of Boosting Distributed Service Resilience. 25th IEEE International Conference on Distributed Computing Systems (ICDCS 2005), Columbus, OH, pages 39-48, June 6-10, 2005.
113. Paul C. Attie. On the Implementation Complexity of Specifications of Concurrent Programs. Distributed Computing (DISC 2003: 17th International Symposium on Distributed Computing, Sorrento, Italy, October 2003), volume 2848 of Lecture Notes in Computer Science, pages 151-165, Springer-Verlag, 2003.

114. Paul C. Attie and Nancy A. Lynch. Dynamic Input/Output Automata: a Formal Model for Dynamic Systems. In K. G. Larsen and M. Nielsen, editors, CONCUR 2001 - Concurrency Theory: 12th International Conference on Concurrency Theory, Aaalborg, Denmark, August 20-25, 2001, Proceedings, volume 2154 of Lecture Notes in Computer Science, pages 137-151, 2001. Springer-Verlag.
115. Mohsen Bahramgiri, Mohammad Taghi Hajiaghayi, and Vahab S. Mirrokni. Fault-tolerant and 3-Dimensional distributed topology control algorithms in wireless multi-hop networks. Proceedings of the 11th IEEE International Conference on Computer Communications and Networks (IC3N), pages 392-398, October 14-16, 2002, Miami, Floria. Also, MIT Technical Report MIT-LCS-TR-862, Cambridge, MA 02139, 2002.
116. Omar Bakr and Idit Keidar. Evaluating the Running Time of a Communication Round over the Internet. Proceedings of the 21st ACM Symposium on Principles of Distributed Computing (PODC '02), Monterey, CA, USA, pages 243-252, July 2002.
117. Ziv Bar-Joseph and Idit Keidar and Nancy Lynch. Early-Delivery Dynamic Atomic Broadcast. In D. Malkhi, editor, Distributed Computing (Proceedings of the 16th International Symposium on DIStributed Computing (DISC) October 2002, Toulouse, France), volume 2508 of Lecture Notes in Computer Science, pages 1-16, 2002. Springer-Verlag.
118. Ziv Bar-Joseph, Idit Keidar, Tal Anker, and Nancy Lynch: QoS Preserving Totally Ordered Multicast. 5th International Conference on Principles Of Distributed Systems (OPODIS), pages 143-162, Paris, France, December, 2000.
119. Jacob Beal and Seth Gilbert. RamboNodes for the Metropolitan Ad Hoc Network. Proceedings of the Workshop on Dependability in Wireless Ad Hoc Networks and Sensor Networks, part of the International Conference on Dependable Systems and Networks, Florence, Italy, June-July, 2004. Also, AI Memo: AIM-2003-027.
120. Michael A. Bender, Jeremy T. Fineman, Seth Gilbert, Charles E. Leiserson. On-the-Fly Maintenance of Series-Parallel Relationships in Fork-Join Multithreaded Programs. Sixteenth ACM Symposium on Parallelism in Algorithms and Architectures (SPAA 2004), Barcelona, Spain, pages 133-144, June 27-30, 2004.
121. Michael A. Bender, Jeremy T. Fineman, and Seth Gilbert. Contention Resolution with Heterogeneous Job Sizes. Proceedings of the 14th Annual European Symposium on Algorithms, September, 2006.
122. Andrej Bogdanov, Stephen Garland, and Nancy A. Lynch. Mechanical Translation of I/O Automaton Specifications into First-Order Logic. In Doron Peled, Moshe Y. Vardi, editors, Formal Techniques for Networked and Distributed Systems - FORTE 2002 (Proceedings of the 22nd IFIP WG 6.1 International Conference, Houston, Texas, USA, November 11-14, 2002), volume 2529 of Lecture Notes in Computer Science, pages 364-368, Springer 2002.
123. Ran Canetti, Ling Cheung, Dilsun Kaynar, Moses Liskov, Nancy Lynch, Olivier Pereira, and Roberto Segala. Time-bounded Task-PIOAs: A Framework for Analyzing Security Protocols. 20th International Symposium on Distributed Computing (DISC 2006), Stockholm, Sweden, September 18-20, 2006. Invited paper.

124. Ran Canetti, Ling Cheung, Dilsun Kaynar, Moses Liskov, Nancy Lynch, Olivier Pereira, and Roberto Segala. Task-Structured Probabilistic I/O Automata. Proceedings the 8th International Workshop on Discrete Event Systems (WODES'06), Ann Arbor, Michigan, July, 2006.
125. Ran Canetti, Ling Cheung, Dilsun Kaynar, Moses Liskov, Nancy Lynch, Olivier Pereira, Roberto Segala. Using Task-Structured Probabilistic I/O Automata to Analyze Cryptographic Protocols. In V. Cortier, S. Kremer, editors, Workshop on Formal and Computational Cryptography - FCC 2006, pages 34--39, July 2006.
126. Michael Bender, Jeremy Fineman, Seth Gilbert, and Bradley Kuszmaul. Concurrent Cache-Oblivious B-Trees. 17th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA 2005), Las Vegas, Nevada, July 2005.
127. Ling Cheung, Nancy Lynch, Roberto Segala, and Frits Vaandrager. Switched Probabilistic I/O Automata. In Z. Liu and K. Araki, editors, Proceedings of the First International Colloquium on Theoretical Aspects of Computing (ICTAC2004), Guiyang, China, September 2004, volume 3407 of Lecture Notes in Computer Science, pages 494-510, Springer-Verlag, 2005.
128. Gregory Chockler, Seth Gilbert, and Boaz Patt-Shamir. Communication-Efficient Probabilistic Quorum Systems. Proceedings of the IEEE International Workshop on Foundations and Algorithms for Wireless Networking (FAWN), March 29-31, 2006.
129. Gregory Chockler, Nancy Lynch, Sayan Mitras, and Joshua Tauber. Proving Atomicity: An Assertional Approach DISC 2005: 19th International Symposium on Distributed Computing, Cracow, Poland, September 2005.
130. G. Chockler, M. Demirbas, S. Gilbert, and C. Newport. A Middleware Framework for Robust Applications in Wireless Ad Hoc Networks. Allerton Conference 2005: Forty-Third Annual Allerton Conference on Communication, Control, and Computing, September 2005.
131. Gregory Chockler, Murat Demirbas, Seth Gilbert, Nancy Lynch, Calvin Newport, and Tina Nolte. Reconciling the Theory and Practice of (Un)Reliable Wireless Broadcast. Proceedings of the 4th International Workshop on Assurance in Distributed Systems and Networks (ADSN 2005), June 6, 2005, Columbus, Ohio, USA.
132. Gregory Chockler, Murat Demirbas, Seth Gilbert, Calvin Newport, and Tina Nolte. Consensus and Collision Detectors in Wireless Ad Hoc Networks. Twenty-Fourth Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2005), Las Vegas, Nevada, pages 197-206, July 2005.
133. Gregory Chockler, Seth Gilbert, Vincent Gramoli, Peter Musial, and Alexander Shvartsman. Reconfigurable Distributed Storage for Dynamic Networks. 9th International Conference on Principles of Distributed Systems (OPODIS 2005), Pisa, Italy, December 12-14, 2005.
134. Gregory Chockler, Idit Keidar , and Dahlia Malkhi. Optimal Resilience Wait-Free Storage from Byzantine Components: Inherent Costs and Solutions. FuDiCo II: S.O.S. Survivability: Obstacles and Solutions. 2nd Bertinoro Workshop on Future Directions in Distributed Computing, Bertinoro (Forli), Italy, June 2004.
135. Murat Demirbas, Anish Arora, Tina Nolte, and Nancy Lynch. A Hierarchy-based Fault-local Stabilizing Algorithm for Tracking in Sensor Networks. In Teruo

Higashino, editor, Principles of Distributed Systems: OPODIS 2004: 8th International Conference on Principles of Distributed Systems, Grenoble, France, December 15-17, 2004, volume 3544 of Lecture Notes in Computer Science, pages 299-315, 2005. Springer.

136. Murat Demirbas, Anish Arora, Tina Nolte, and Nancy Lynch. Brief Announcement: STALK: A Self-Stabilizing Hierarchical Tracking Service for Sensor Networks. Proceedings of the 23rd Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2004), St. John's, Newfoundland, Canada, page 378, July 25-28, 2004.
137. Shlomi Dolev, Limor Lahiani, Nancy Lynch, and Tina Nolte. Self-Stabilizing Mobile Node Location Management and Message Routing. SSS 2005: Seventh International Symposium on Self-Stabilizing Systems, Barcelona, Spain, October 2005.
138. Shlomi Dolev, Seth Gilbert, Limor Lahiani, Nancy Lynch, and Tina Nolte. Timed Virtual Stationary Automata for Mobile Networks. 9th International Conference on Principles of Distributed Systems (OPODIS 2005), Pisa, Italy, December 12-14, 2005.
139. Shlomi Dolev, Seth Gilbert, Limor Lahiani, Nancy Lynch, and Tina Nolte. Timed Virtual Stationary Automata for Mobile Networks. Allerton Conference 2005: Forty-Third Annual Allerton Conference on Communication, Control, and Computing, September 2005. Invited paper.
140. Shlomi Dolev, Seth Gilbert, Elad Schiller, Alex A. Shvartsman, and Jennifer Welch. Autonomous Virtual Mobile Nodes. DIAL-M-POMC 2005: Third Annual ACM/SIGMOBILE International Workshop on Foundation of Mobile Computing, Cologne, Germany, September 2, 2005.
141. Shlomi Dolev, Seth Gilbert, Elad Schiller, Alex Shvartsman, Jennifer Welch. Brief Announcement: Autonomous Virtual Mobile Nodes. 17th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA 2005), Las Vegas, Nevada, July 2005.
142. Shlomi Dolev, Limor Lahiani, Seth Gilbert, Nancy Lynch, Tina Nolte. Brief Announcement: Virtual Stationary Automata for Mobile Networks. Proceedings of the 24th Annual ACM Symposium on Principles of Distributed Computing (PODC'05), Las Vegas, Nevada, July, 2005.
143. Shlomi Dolev, Seth Gilbert, Nancy A. Lynch, Elad Schiller, Alex A. Shvartsman, and Jennifer L. Welch. Virtual Mobile Nodes for Mobile Ad Hoc Networks. 18th International Symposium on Distributed Computing (DISC04), Trippenhuis, Amsterdam, the Netherlands, October 4-7, 2004. Also, in Rachid Guerraoui, editor, volume 3274 of Lecture Notes in Computer Science, Springer-Verlag, December 2004.
144. Shlomi Dolev, Seth Gilbert, Nancy Lynch, Elad Schiller, Alex Shvartsman, Jennifer Welch. Brief Announcement: Virtual Mobile Nodes for Mobile Ad Hoc Networks. Proceedings of the 23rd Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2004), St. John's, Newfoundland, Canada, page 385, July 25-28, 2004. Also, Technical Report MIT-LCS-TR-937, MIT CSAIL, Cambridge, MA, 2004.

145. Shlomi Dolev, Seth Gilbert, Nancy Lynch, Alex Shvartsman, and Jennifer Welch. GeoQuorums: Implementing Atomic Memory in Ad Hoc Networks. In Faith Fich, editor, Distributed Computing (DISC 2003: 17th International Symposium on Distributed Computing, Sorrento, Italy, October, 2003), volume 2848 of Lecture Notes in Computer Science, pages 306-320, Springer-Verlag, 2003.
146. Buckhard Englert and Alexander A. Shvartsman. Graceful Quorum Reconfiguration in a Robust Emulation of Shared Memory. International Conference on Distributed Computer Systems (ICDCS'2000), pages 454-463, 2000.
147. Rui Fan and Nancy Lynch. An $\Omega(n \log n)$ Lower Bound on the Cost of Mutual Exclusion. Proceedings of the Twenty-Fifth Annual Symposium on Principles of Distributed Computing (PODC'06), Denver, Colorado, July 2006. Best Student Paper Award.
148. Rui Fan, Indraneel Chakraborty, and Nancy Lynch. Clock Synchronization for Wireless Networks. In Teruo Higashino, editor, Principles of Distributed Systems: OPODIS 2004: 8th International Conference on Principles of Distributed Systems, Grenoble, France, December 15-17, 2004, volume 3544 of Lecture Notes in Computer Science, pages 400-414, 2005. Springer.
149. Rui Fan and Nancy Lynch. Gradient Clock Synchronization. Proceedings of the Twenty-Third Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC 2004)), St. John's, Newfoundland, Canada, pages 320-327, July 25-58, 2004. Best Student Paper Award.
150. Rui Fan and Nancy Lynch. Efficient Replication of Large Data Objects. Distributed Computing (DISC 2003: 17th International Symposium on Distributed Computing, Sorrento, Italy, October, 2003), volume 2848 of Lecture Notes in Computer Science, pages 75-91, Springer-Verlag, 2003.
151. Rui Fan and Nancy Lynch. Efficient replication of large data objects. Proceedings of the Twenty-Second Annual ACM Symposium on Principles of Distributed Computing, Boston, Massachusetts, page 335, July 2003.
152. Alan Fekete and Idit Keidar: A Framework for Highly Available Services Based on Group Communication. IEEE International Workshop on Applied Reliable Group Communication (WARGC), pages 57-62, held in conjunction with ICDCS 2001, April 2001.
153. Matthias Fitzi, Daniel Gottesman, Martin Hirt, Thomas Holenstein, and Adam Smith. Detectable Byzantine Agreement Secure Against Faulty Majorities. In Proceedings of the Twenty-First ACM Symposium on Principles of Distributed Computing (PODC 2002), Monterey, CA, July, 2002.
154. Stephen J. Garland and Nancy A. Lynch and Mandana Vaziri. IOA: A Language for Specifying, Programming and Validating Distributed Systems. User and Reference Manual. Laboratory for Computer Science, Massachusetts Institute of Technology, Cambridge, MA 02139, October 2001.
155. Chryssis Georgiou, Peter M. Musial, and Alexander A. Shvartsman. Long-Lived Rambo: Trading Knowledge for Communication. Rastislav Kralovic, Ondrej Sykora (Eds.): Structural Information and Communication Complexity, 11th International Colloquium, SIROCCO 2004, Smolenice Castle, Slowakia, June 21-

23, 2004, volume 3104 of Lecture Notes in Computer Science, pages 185-196, Springer 2004.

156. Ch. Georgiou, A. Russell and A. Shvartsman. Work-Competitive Scheduling for Cooperative Computing with Dynamic Groups. The Thirty-Fifth Annual ACM Symposium on Theory of Computing (STOC'2003), pages 251-258, San Diego, CA, June 2003.
157. Seth Gilbert, Rachid Guerraoui, and Calvin Newport. Of Malicious Motes and Suspicious Sensors: On the Efficiency of Malicious Interference in Wireless Networks. Proceedings of the 10th International Conference On Principles Of Distributed Systems (OPODIS), Bordeaux, France, December 12-15, 2006.
158. Seth Gilbert and Gregory Malewicz. The Quorum Deployment Problem. OPODIS 2004: 8th International Conference on Principles of Distributed Systems, Grenoble, France, December 15-17, 2004. Also, full version in MIT CSAIL Technical Report MIT-LCS-TR-972, October 2004.
159. Seth Gilbert, Nancy Lynch, and Alex Shvartsman. RAMBO II: Rapidly Reconfigurable Atomic Memory for Dynamic Networks. Proceedings of the International Conference on Dependable Systems and Networks (DSN), San Francisco, CA, pages 259-268, June 22nd - 25th, 2003.
160. Mohammad Taghi Hajiaghayi, Nicole Immorlica, and Vahab S. Mirrokni. Power optimization in fault-tolerant topology control algorithms for wireless multi-hop networks. MOBICOM 2003: Proceedings of the Ninth Annual ACM International Conference on Mobile Computing and Networking, pages 300-312, San Diego, CA, September 2003.
161. Kyle Ingols and Idit Keidar: Availability Study of Dynamic Voting Algorithms. 21st IEEE International Conference on Distributed Computing Systems (ICDCS), pages 247-254, April 2001. Previous version: MIT Technical Memorandum MIT-LCS-TM-611, November 2000.
162. Yoshinobu Kawabe and Ken Mano. Verifying the Nepi network programming system with IOA-Toolkit. Proceedings of the 9th Workshop on Foundations of Software Engineering (FOSE '02), 2002. In Japanese.
163. Dilsun K. Kaynar and Nancy A. Lynch. Decomposing Verification of Timed I/O Automata. Formal Techniques, Modelling and Analysis of Timed and Fault Tolerant Systems: Joint International Conferences on Formal Modeling and Analysis of Timed Systems, FORMATS 2004, and Format Technicques in Real-Time and Fault-Tolerant Systems, FTRTFT 2004, Grenoble, France, September 22-24, 2004. Volume 3253 of Lecture Notes in Computer Science, pages 84-101, Springer-Verlag, 2004.
164. Dilsun Kaynar, Nancy Lynch, and Sayan Mitra. Specifying and Proving Timing Properties with TIOA Tools. 25th IEEE International Real-Time Systems Symposium, Work in Progress Session (RTSS 2004 WIP), December 5-8 2004, Lisbon, Portugal.
165. Dilsun K. Kaynar, Nancy Lynch, Roberto Segala, and Frits Vaandrager. Timed I/O Automata: A Mathematical Framework for Modeling and Analyzing Real-Time Systems. RTSS 2003: The 24th IEEE International Real-Time Systems Symposium, Cancun, Mexico, pages 166-177, December, 2003. IEEE Computer Society. (Full version available as Technical Report MIT/LCS/TR-917.)

166. Dilsun Kirli Kaynar, Anna Chefter, Laura Dean, Stephen J. Garland, Nancy A. Lynch, Toh Ne Win, and Antonio Ramirez-Robredo. Simulating Nondeterministic Systems at Multiple Levels of Abstraction. In Tools Day held in conjunction with CONCUR'02, Brno, Czech Republic, August 2002.
167. Idit Keidar. Challenges in Evaluating Distributed Algorithms. FuDiCo 2002: Proceedings of the International Workshop on Future Directions in Distributed Computing (FuDiCo 2002), June 2002, Bertinoro, Italy.
168. I. Keidar and K. Marzullo. The Need for Realistic Failure Models in Protocol Design. Position paper in the 4th International Survivability Workshop (ISW) 2001/2002, March 2002.
169. Roger Khazan and Nancy Lynch. An Algorithm for an Intermittently Atomic Data Service Based on Group Communication. Proceedings of the International Workshop on Large-Scale Group Communication, Florence, Italy, pages 25-30, October 2003.
170. Ben Leong, Sayan Mitra, and Barbara Liskov. Path vector face routing: Geographic routing with local face information. Proceedings of 13th IEEE International Conference on Network Protocols (ICNP'05), November 6-9, 2005, Boston, Massachusetts, USA.
171. Matthew Lepinski, David Liben-Nowell, Seth Gilbert, and April Rasala Lehman. Playing Games in Many Possible Worlds. Proceedings of the Seventh ACM Conference on Electronic Commerce, June, 2006.
172. Hongping Lim, Dilsun Kaynar, Nancy Lynch, and Sayan Mitra. Translating timed I/O automata specifications for theorem proving in PVS. Proceedings of International Conference on Formal Modelling and Analysis of Timed Systems (FORMATS'05), Uppsala, Sweden, September 26 - 28, 2005.
173. Carl Livadas and Idit Keidar. Caching-Enhanced Scalable Reliable Multicast. International Conference on Dependable Systems and Networks (DSN), June-July 2004.
174. Carolos Livadas and Nancy A. Lynch. A Formal Venture into Reliable Multicast Territory. In Doron Peled, Moshe Y. Vardi, editors, Formal Techniques for Networked and Distributed Systems - FORTE 2002 (Proceedings of the 22nd IFIP WG 6.1 International Conference, Houston, Texas, USA, November 11-14, 2002), volume 2529 of Lecture Notes in Computer Science, pages 146-161, Springer 2002. Also, full version as Technical Report MIT-LCS-TR-868, MIT Laboratory for Computer Science, Cambridge, MA, November 2002.
175. Carolos Livadas, Idit Keidar, and Nancy A. Lynch. Designing a Caching-Based Reliable Multicast Protocol. Proceedings of the International Conference on Dependable Systems and Networks (DSN'01), Fast Abstracts Supplement, pages B44-B45, Gothenburg, Sweden, July 2001.
176. Nancy Lynch, Sayan Mitra, and Tina Nolte. Motion Coordination Using Virtual Nodes. CDC-ECC 2005: Forty-Fourth IEEE Conference on Decision and Control and European Control Conference, Seville, Spain, December 2005. Invited paper.
177. Nancy Lynch. Working with Mike on Distributed Computing Theory, 1978-1992. Proceedings of the Twenty-Second Annual ACM Symposium on Principles of Distributed Computing (PODC'03), page 11, Boston, MA, July 2003.

178. Nancy Lynch, Roberto Segala, and Frits Vaandrager. Compositionality for Probabilistic Automata. In Roberto Amadio and Denis Lugiez, editors, CONCUR 2003 - Concurrency Theory (14th International Conference on Concurrency Theory, Marseille, France, September, 2003), volume 2761 of Lecture Notes in Computer Science, pages 208-221, Springer-Verlag, 2003. Also, long version as Technical Report MIT-LCS-TR-907, MIT Laboratory for Computer Science, Cambridge, MA.
179. Nancy Lynch, Dahlia Malkhi, David Ratajczak. Atomic Data Access in Content Addressable Networks. In P. Druschel, F. Kaashoek, and A. Rowstron, editors, Peer-to-Peer Systems (First International Workshop on Peer-to-Peer Computing, Cambridge, MA, March 2002), volume 2429 of Lecture Notes in Computer Science, pages 295-305, Springer, 2002.
180. Nancy Lynch and Alex Shvartsman. Communication and Data Sharing for Dynamic Distributed Systems. In A. Schiper, A.A. Shvartsman, H. Weatherspoon, B.Y. Zhao, editors, Future Directions in Distributed Computing: Research and Position Papers (FuDiCo 2002: Proceedings of the International Workshop on Future Directions in Distributed Computing, Bertinoro,Italy, June 2002), volume 2584 of Lecture Notes in Computer Science, pages 62-67, Springer-Verlag, 2003.
181. Nancy Lynch and Alex Shvartsman. RAMBO: A Reconfigurable Atomic Memory Service for Dynamic Networks. In D. Malkhi, editor, Distributed Computing (Proceedings of the 16th International Symposium on DIStributed Computing (DISC) October 2002, Toulouse, France), volume 2508 of Lecture Notes in Computer Science, pages 173-190, 2002. Springer-Verlag. Also, Technical Report MIT Laboratory for Computer Science, Technical Report MIT-LCS-TR-856, Cambridge, MA, 2002.
182. Nancy Lynch, Roberto Segala, and Frits Vaandrager. Hybrid I/O Automata Revisited. In Maria Domenica Di Benedetto and Alberto Sangiovanni-Vincentelli, editors Hybrid Systems: Computation and Control. Fourth International Workshop (HSCC'01, Rome, Italy, March 2001, volume 2034 of Lecture Notes in Computer Science, pages 403-417, 2001. Springer-Verlag. Postscript. Long version is Technical Report MIT/LCS/TR-827, MIT Laboratory for Computer Science, July 2001.
183. Sayan Mitra and Nancy Lynch. Approximate simulations for task-structured probabilistic I/O automata. LICS workshop on Probabilistic Automata and Logics (PAul06), Seattle, WA, August 2006.
184. Sayan Mitra, Daniel Liberzon, and Nancy Lynch. Verifying average dwell time by solving optimization problems. In Ashish Tiwari and Joao P. Hespanha, editors, Hybrid Systems: Computation and Control (HSCC 06) Santa Barbara, CA, March 2006, volume 3927 of Lecture Notes in Computer Science, pages 476-490, 2006. Springer.
185. Sayan Mitra and Daniel Liberzon. Stability of Hybrid Automata with Average Dwell Time: An Invariant Approach. Proceedings of the 43rd Conference on Decision and Control, Paradise Island, Bahamas, December, 2004.
186. Sayan Mitra and Myla Archer. Reusable PVS Proof Strategies for Proving Abstraction Properties of I/O Automata. STRATEGIES 2004, IJCAR Workshop on Strategies in Automated Deduction, Cork Ireland, July 2004.

187. Sayan Mitra and Jesse Rabek. Energy Efficient Connected Clusters for Mobile Ad Hoc Networks. MED-HOC-NET 2004, Third Annual Mediterranean Ad Hoc Networking Workshop, Bodrum, Turkey, June 2004.
188. Sayan Mitra, Yong Wang, Nancy Lynch, and Eric Feron. Safety Verification of Model Helicopter Controller using Hybrid Input/Output Automata. O. Maler, A. Pnueli, editors, Hybrid Systems: Computation and Control (6th International Workshop, HSCC'03, Prague, the Czech Republic April 3-5, 2003), volume 2623 of Lecture Notes in Computer Science, pages 343-358, Springer-Verlag, 2003.
189. Sayan Mitra and Myla Archer. Developing Strategies for Specialized Theorem Proving about Untimed, Timed, and Hybrid I/O Automata. In STRATA 2003, Design and Application of Strategies/Tactics in Higher Order Logics, Rome, Italy, September, 2003.
190. P.M. Musial and A.A. Shvartsman. Implementing a Reconfigurable Atomic Memory Service for Dynamic Networks. In Proceedings of the 18'th International Parallel and Distributed Processing Symposium (IPDPS'04) --- FTPDS WS, Santa Fe, New Mexico, pages 208-215, April, 2004.
191. A. Russell and A. Shvartsman. Distributed Computation Meets Design Theory: Local Scheduling for Disconnected Cooperation. Current Trends in Theoretical Computer Science: The Challenge of the New Century, vol. 1: Algorithms and Complexity, pp. 315-336, World Scientific, 2004.
192. Joshua A. Tauber and Nancy A. Lynch and Michael J. Tsai. Compiling IOA without Global Synchronization. Proceedings of the 3rd IEEE International Symposium on Network Computing and Applications (IEEE NCA04), Cambridge, MA, August 2004.
193. Shinya Umeno and Nancy Lynch. Proving safety properties of an aircraft landing protocol using I/O Automata and the PVS theorem prover: a case study. FM 2006: Formal Methods, International Symposium of Formal Methods Europe, Hamilton, Ontario Canada, August, 2006. Volume 4085 of Lecture Notes in Computer Science, pages 64-80, Springer, 2006.
194. Toh Ne Win, Michael D. Ernst, Stephen J. Garland, Dilsun K. Kaynar, and Nancy Lynch. Using simulated execution in verifying distributed algorithms. In L.D. Zuck, P.C. Attie, A. Cortesi, S. Mukhopadhyay, editors, Verification, Model Checking, and Abstract Interpretation (Proceedings of 4th International Conference, VMCAI 2003, New York, NY, USA, January 9-11, 2003), volume 2575 of Lecture Notes in Computer Science, pages 283-297, Springer-Verlag, 2003.